ASTRONOMY

DUPUIS

Page 75, 10th line from bottom, for "solstices" read equinoxes."

Page 84, 17th line from top, for "fact" read "fast."

Page 91, 18th line from bottom, for "50°.1" read "50″.1."

Page 109, 10th line from bottom, for "he" read "the."

Page 182, 5th line from top, for "southern" read "northern."

Page 201, 2nd line from bottom, for "comit" read "comet."

BOOKS BY THE SAME AUTHOR.

SYNTHETIC GEOMETRY OF THE POINT, LINE AND CIRCLE, 294 pp. Price $1.10.

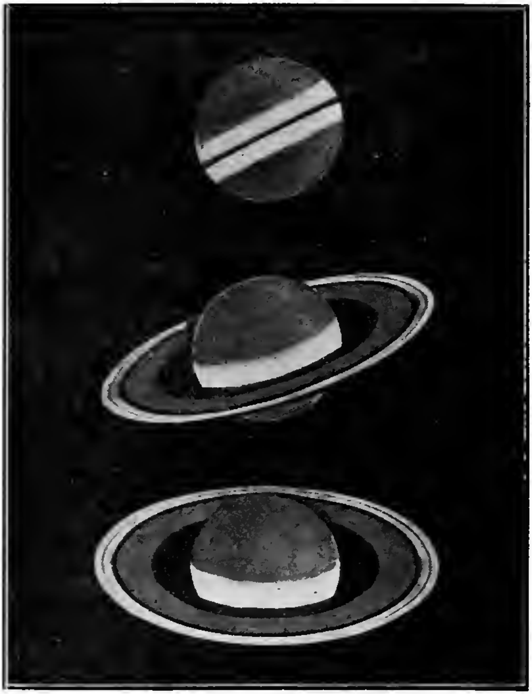
ELEMENTS OF SYNTHETIC SOLID GEOMETRY, 238 pp. Price $1.60.

THE PRINCIPLES OF ELEMENTARY ALGEBRA, 336 pp. Price $1.10.

PLANE TRIGONOMETRY FOR PRACTICAL SCIENCE STUDENTS, 79 pp. Price $1.00.

SPHERICAL TRIGONOMETRY AND ASTRONOMY FOR PRACTICAL SCIENCE STUDENTS, 92 pp. Price $1.00.

THE ELEMENTS OF ASTRONOMY



THE

Elements of Astronomy

PRINCIPALLY ON THE MECHANICAL SIDE

INTENDED FOR

ENGINEERING STUDENTS

BY

N. F. DUPUIS, M.A., LL.D., F.R.S.C.

R. UGLOW & COMPANY
KINGSTON, ONT.
1910

A

Printed and bound at The Jackson Press, Kingston.

PREFACE.

This book is the outcome of a course of lectures delivered for a number of years to Engineering students in the first year of their course. It deals principally with the mechanical side of astronomy, as that is the side, in the opinion of the author, most cognate to engineering education. As a consequence, the hypothetical side of astronomy, embracing theories in regard to stars, nebulae, comets, etc., has not been given the place of prominence, but has been assigned to the latter pages of the work, where it is dealt with as fully as circumstances would permit.

A limited amount of mathematical work appears in the book, but it is all of the simplest kind, involving only elementary arithmetic, algebra and geometry.

N. F. D.

KINGSTON, Nov. 1st, 1910.

ERRATA.

Page 172, fourth line from top, for "7" read 3½.

Page 187, third line from bottom, for *distant* read *distinct.*

ASTRONOMY.

Astronomy ranks amongst the oldest of the sciences. It is older than any fixed system of Theology, and coeval with religion in its origin. The earliest religious worship was more or less immediately concerned with legends and stories and speculations upon the origin and purpose of the universe, and upon the natures and functions of the sun, moon, and stars. And some echoes of the music of that ancient worship have come down, through all the intervening ages, to the present time.

The Astronomic field is unbounded, reaching to the utmost limits of vision, and vision enhanced by the most powerful telescopes. Astronomic phenomena are silent and yet grand and impressive. The roseate hue of the morning, the daily rising and setting of the glorious light-giving and life-giving sun, the monthly waxing and waning of the moon, the ever-recurring round of the bountiful and changing year, the nightly pageant of the stars have been things of wonder and admiration in all ages, and the interest in them is not yet and never will be abated.

The progress of astronomy in modern times has had a most important effect upon ancient notions of things in general and upon early and mediaeval theological dogma. For this progress has shown that this earth is not a plane, that it is not fixed in space, and that it is not the centre of the universe or even of the solar system, as it was formerly believed to be. And thus the study of astronomy has freed mankind from many a mistaken notion in regard to the nature of the universe and the earth's importance in it, as well as from many superstitions and pseudo-theological ideas which, although long held as religious dogmas, were not reasonable, and in some cases not conceivable.

But the universe is very reticent and reveals little to us spontaneously. A cursory view may give us some ideas, but often these are apt to be more or less false. For in the sub-

ject of astronomy especially are first appearances deceptive. To arrive at truthful conclusions requires much sifting of evidence, together with close observation and logical reasoning.

The earth upon which we are compelled to live bulks so large in comparison with every other thing in sight that we are naturally inclined to look upon it as the specially important object in the universe. In one sense, as our home and the locality where our lives are lived, our work is done, and our observations are made, it is. But to an eye that could look at the whole from a very far-off point of view and see things in their proper perspective, the earth would become a very insignificant body in comparison with myriads of others which dot the infinite spaces of the universe.

THE STARS.

No person with a due sense of beauty can look upward on a clear and moonless night without being impressed with the glory and the beauty of the stars. They appear of all sizes, from those barely visible to the eye to those like Sirius which seem to rejoice in their brilliancy, and their arrangement over the visible heavens appears to be devoid of all system.

But the stars are to us not only beautiful, they are useful as well. They form the landmarks on the celestial vault, the figures on the dial of the universe, and without their presence the study of exact astronomy would scarcely be possible. It is necessary, then, that at the very beginning of the subject we learn something about the stars.

A very little imagination will enable a person to arrange some of the stars into something like natural groups, and some astronomers of the past, with very active and lively imaginations, so arranged all the stars, naming the groups after animals, or persons, or objects which they were thought to resemble in outline, or people or things which they desired to honor, or possibly in some cases from mere fanciful ideas. Thus we have such groups or constellations as *Ursa Major* (the great bear), *Orion* (the name of a fabled hunter), *Canis Major* (the big dog), *Aquila* (the eagle), *Perseus* (the

name of an ancient hero), *Scorpio* (the scorpion), etc. Each such group is called a *constellation.*

The accompanying figure gives the principal stars and their arrangement in a few of the more prominent of the groups.

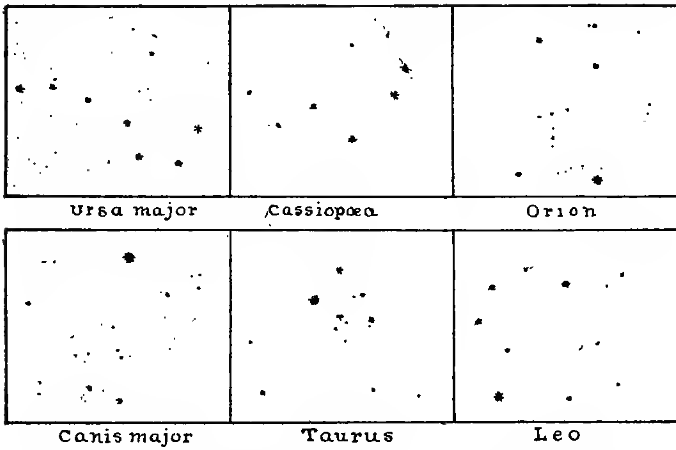


Fig. 1.

This way of grouping the stars is unscientific, and upon the whole somewhat silly, especially in regard to nomenclature. But, originating in very early times, it has been so long in use, and the names of the constellations and even of some of the principal stars, have become so well established in astronomical usage, that it would now appear as a sort of sacrilege to abandon them. Thus *Orion* and *Arcturus,* the name of a well-known constellation and the name of a bright star, are mentioned in the book of Job, and the whole lot of them are too intimately woven into the history of astronomy to be now discarded.

The number of stars visible to the unaided eye is very deceptive. To the superficial observer this number appears to run far up into the thousands, but an actual count will show that a normal eye cannot see more than from 1,000 to 1,500 at any one time. And as we can see only one-half of

the whole heavens at once, the total number of stars visible in both hemispheres will vary from 2,000 to 3,000, depending on the quality of the observer's eye. Under even moderate powers of the telescope this number becomes wonderfully increased, and under high powers the celestial vault appears quite crowded with stars.

By the application of photography things are carried still farther, for it is possible to photograph objects which are quite invisible to the eye, and it has been estimated that upwards of a hundred million stars may be made to give a record of themselves by means of the highly sensitized photographic plate used in conjunction with the telescope. And most of the important work being done in stellar astronomy at the present time is carried on by means of the telescope, the photographic plate and the spectroscope.

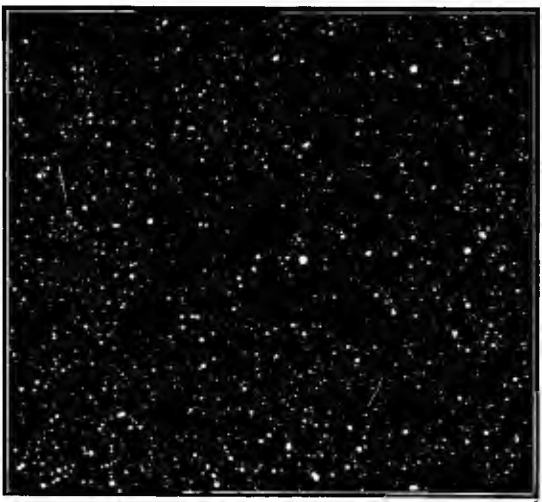


Fig. 2.

The stars are variously distributed through the depths of space as well as through its breadth, some of them being

hundreds, and possibly thousands of times as distant as others; but to us they all appear to lie upon the surface of a great sphere having the earth as its centre. This apparent sphere is called the sphere of the heavens, or *the celestial sphere,* as distinguished from the earth itself which is called *the terrestrial sphere.*

For all practical purposes the sphere of the heavens may be taken to be infinitely distant, and two lines from any two points on the earth to the same star are practically parallel.

One prominent thing in regard to the stars must be noted, that is their relative fixity, on account of which they have received the name of fixed stars.

However often the stars are observed, whether at intervals of a year, or of ten years, they appear to hold almost absolutely the same relative positions in the heavens. In fact, the great constellations are practically the same to us as they were to the ancient Babylonians 5,000 years ago. This does not mean that the stars are in any way attached to one another, or that they do not partake of individual and independent movement. It means merely that the movements of the stars, relatively to one another, are so minute as seen from our distance, that whole ages must pass away before their displacement becomes sensible to a superficial observer. These displacements, however, although small, when considered from year to year, are accumulative and have to be recorded and accounted for by the professional astronomer.

Practically then we may say that the stars are fixed in the heavens, or in relation to one another without introducing any serious errors into any results which may appear in this work, and it is with reference to the stars as a whole that direction in the universe is to be fixed.

THE EARTH.

The astronomical symbol for the earth is ⊕.

The first impression formed in looking around over the country is that the earth is an extended plane broken by

hill and valley. And this was pretty much the view held by all primitive people who had departed from savagery sufficiently far to notice things, for it would not be safe to say what views a savage may hold.

As there appear to be some primitive people yet, even amongst civilized communities, it may be well to show why the astronomer believes that the earth, broadly speaking, is not a plane either extended or limited, but that it has approximately the form of a sphere.

(*a*) If the earth is a plane it cannot be indefinitely extended. For the sun, moon, and stars pass below it in the western and rise from below it in the eastern part of the heavens every twenty-four hours; and no intelligent person is likely to contend that the sun which sets in the evening is not the same sun as that which rises the next morning, or that the moon and stars are renewed daily.

And if the plane is limited, travellers going far enough east or west should come to its border or edge, a sort of jumping-off place which forbids any further progress in that direction. On the contrary, such travellers, after a time, invariably return to their starting point, and in a direction which plainly shows that they have gone around the world.

(*b*) On an extended plane high mountains such as the Andes or the Rockies should be visible for at least a thousand miles. But such is not the case. The highest mountain in the world, Mount Everest, cannot be seen at a greater distance than about 200 miles, and then it is only the top that appears above the distant scene.

That the absorptive effects of the atmosphere upon the light coming from distant objects is an argument for the non-appearance of distant mountains, is not tenable. For it fails to explain why the tops only of such mountains are visible while their sides are concealed; besides, the moon and bright stars are much farther away than any mountain, and yet they can be seen when quite close to the horizon, if clouds do not intervene.

(*c*) In the surface of still water we have a something which expresses what may be called the average form of the

earth's surface freed from its elevations and depressions and all its irregularities.

When we stand upon the shore of the ocean, or of some great lake like Ontario, we see at some distance a line where the sky and the water appear to meet. This line is the *offing,* and it marks the extreme distance at which the surface of the water is visible.

If a large steamer is going out, we notice that it appears to grow smaller and to rise until the offing is reached, after which, while still decreasing in size, it appears to sink behind the intervening water, and we may see the smoke from the funnel for some time after the vessel has completely disappeared, just as we may see the smoke from the chimney of a house when the house itself is hidden behind a hill.

Fig. 3.

(*d*) When we are upon the open sea, out of sight of land, the sea-offing extends completely around us so as to form a circle with ourselves at the centre. And as we sail onwards from day to day the offing, although travelling forwards with the ship, remains circular. And this holds true for every ocean in the world.

But a body which always, and from all points of view, presents a circular outline must be a sphere. And we conclude that the surface of the ocean is, approximately at least, of a spherical form.

(*e*) Some interesting problems in engineering arise out of this curvature of the surface of a body of water, and these problems, in themselves, bear evidence to the earth's rotundity. Thus a "level line" as determined by the engineer's

level is a tangent to the earth's surface at the point of observation, and if the earth were a plane this line would coincide with a water surface for any distance. But if such a line be sighted across a lake several miles in width it is quite apparent that the height of the line above the water is greater upon the further side of the lake than it is at the point of observation.

Again, if the bottom of a canal, several miles long, be made parallel to the engineer's " level line," it is well known that the water in the canal will not be of uniform depth throughout, but will get shallower as we recede from the starting point. And it is found necessary, in order to prevent this, to drop the bottom of the canal eight inches at the end of the first mile, and from this point to adopt a new level line, and to continue this process.

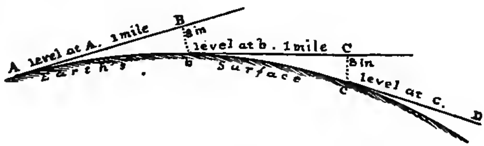


Fig. 4.

Thus if *A* be the starting point and *AB* be one mile in length and parallel to the level line at *A*, the water at *B* will be 8 inches shallower than at *A*. It becomes necessary then to drop 8 inches from *B* to *b* and make *b* a new starting point for the level line *bC*, etc.

Of course, in practice the engineer avoids the abrupt drops of 8 inches at *B*, *C*, etc., by distributing them throughout the whole extent of the canal.

(*f*) All the heavenly bodies which are sufficiently near to us to have their form certainly determined are spherical or nearly so, as the sun, the moon, and all the visible planets, and from analogy we would infer that the earth also has a spherical form.

These, and other considerations which will appear from time to time in the sequel, should be sufficient to remove any doubt as to the spherical form of the earth.

1. Gravitation—Up and Down.

One of the chief difficulties, at least with beginners, is as to how people manage to live upon and cling to different and even opposite sides of a body having a spherical form.

The difficulty arises from want of a clear conception of what is meant, fundamentally, by *up* and *down*. These terms do not denote absolute directions, but directions relative to the earth's surface.

Matter in bulk has a tendancy to draw together, to aggregate. If a single material body were placed in space it could have no relations except to itself. But if a second material body be there, the two would exercise an attraction or pull upon each other, and if nothing intervened to prevent it the bodies would in due time come together to form a single body.

This general form of attraction of matter for matter is known as the *attraction of gravitation,* or simply *gravitation.* Its existence is not a matter of theory only, as it has been fully established by a classical laboratory experiment known as Cavendish's experiment.

This attraction increases directly as the mass or amount of matter in the attracting body, and it is inversely proportional to the square of the distance through which the attraction takes place.

Thus if m denotes the mass of a body, d denotes the distance of a second body upon which the attraction acts, and a denotes the measure of the attraction, a varies as the quotient of m divided by d^2.

The attraction between two material bodies is mutual; if *A* attracts *B,* so also *B* attracts *A,* and the whole attraction between them is the sum of the individual attractions.

Thus the earth attracts the moon and the moon attracts the earth, but as the earth contains 80 times as much matter as the moon, the pull of the earth on the moon is 80 times as great as the pull of the moon on the earth; and in coming together, if that were possible, the moon would move 80 times as far as the earth.

Now, the mass of the earth is millions of times greater than that of any body upon its surface. So we may say that the earth, by virtue of the attraction of gravitation, draws the bodies on its surface towards its centre of attraction just as a magnet, by virtue of magnetic attraction, draws bits of iron and steel toward its polar centre and causes them to cling to its surface.

Down, then, is the direction of the earth's attraction, and thus upon every part of the earth's surface, *down* is towards the earth's centre of attraction, and *Up* is the opposite of down.

The plumb-line. The 'bob' or weight at the end of the plumb-line tends to get as near to the centre of attraction of the earth as possible, and hence the plumb-line gives the true directions of *up* and *down.*

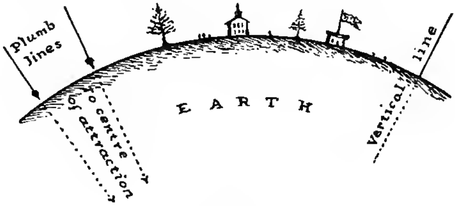


Fig. 5.

From the nature of the case, it is readily seen that the plumb-lines at any two places upon the earth's surface cannot be parallel; for even in case of antipodes, or points on the earth exactly opposite, the lines, although parallel, are stretched by their bobs in opposite directions.

With these conceptions thoroughly mastered there is no difficulty in understanding that all plumb-lines point to the centre of attraction, and that all bodies which stand upright, as trees, columns, spires, human beings, etc., must be approximately parallel to the plumb lines in their vicinity.

Two plumb-lines 69.1 miles apart make an angle of 1° with one another, and if they are one mile apart the angle between them is about 52″.

The level depends for its action on the equilibrium of the surface of a liquid, which tends to accommodate itself to the

Fig. 6.

rotundity of the earth's surface. It consists of a small glass tube very slightly curved and closed at both ends after being filled with a mobile liquid,, alcohol in preference to water, until there is only a small bubble of air left in the tube. The whole is so mounted as to be readily applied to any plane surface.

When the surface is 'level' the bubble stands at the middle position, and any inclination of the plane will cause the bubble to move towards the higher end of the tube. In astronomical instruments the level is a more convenient auxiliary than the plumb-line. And as the level line is perpendicular to the plumb-line, both instruments serve practically the same purpose. A level plane at any point on the earth has the plumb-line at that point as its normal. And hence we see that level planes at any two points on the earth's surface cannot be parallel, unless the two points are antipodal.

Sea level. The word "level" is here used in a somewhat different sense, the whole expression meaning the height or position in elevation of the surface of the sea.

As all the waters of the oceans are connected and continuous, the surface assumes an equilibrium form which expresses the mean form of the earth as a whole, and this surface is the datum surface to which we refer altitudes and depressions. At an inland point sea-level means the position in altitude which would be reached by the surface of the sea if it could be brought to the point by a subterranean channel.

We express the height of a mountain by giving its altitude above the surface of the sea, and not above that of the surrounding country; and we express depressions in like manner.

Many measurements, such as the height of the barometer, the time of oscillation of a pendulum of given length, etc., are affected by altitude, and all such have to be referred to the sea-level, or level of the sea.

2. Horizon, Zenith, Nadir.

The word horizon has a popular meaning and also an astronomical one. Popularly it means the line, or rather circle, which limits our view over the earth's surface, and where the sky and land, or the sky and water, seem to meet. The astronomical meaning of the word is more definite and exact.

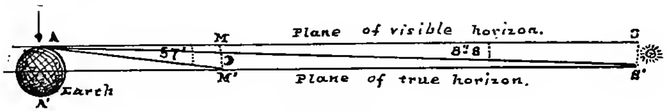


Fig. 7.

Let a plane touching the earth's hypothetical surface, and perpendicular to the plumb-line at *A*, be indefinitely extended. And let another plane, passing through the earth's centre and parallel to the first plane, be similarly extended. Since parallel planes meet at infinity, these two planes practically meet and form one great circle about the heavens where these two planes meet the celestial sphere.

This great circle is the astronomical horizon of the point *A*, as also of the antipodal point *A'*.

As it is convenient at times to refer to these planes, the first will be called the plane of the *visible horizon*, or simply the visible horizon, and the other the plane of the *true* horizon.

The angular distance between these two planes, as seen from *A*, decreases as the distance from the earth increases. Thus, at the distance of the moon this angle, *MAM'*, is about 57', and at the distance of the sun it is only 8".8, while at the distance of the nearest fixed star it is altogether inappreciable, being less than the forty-thousandth part of one second.

We may state the same idea otherwise as follows: When the moon is on the true horizon it is 57′ below the visible horizon; when the sun is on the true horizon it is 8″.8 below the visible horizon; and when a fixed star is on the true horizon it is also on the visible horizon.

The *zenith* of a place on the earth is that point in the celestial sphere to which the plumb-line at the place is directed upwards, that is, it is the point in the heavens directly overhead. And the *nadir* is the point in the celestial sphere to which the plumb-line, at the place, is directed downwards. The zenith and the nadir are opposite points in the celestial sphere. Evidently no two places can have the same zenith, and they can have the same true horizon only when antipodal.

The figure (8) represents a plane section through the centre of the earth, and through the two places *A* and *B* on its surface, and *A* is supposed to be directly north from *B*.

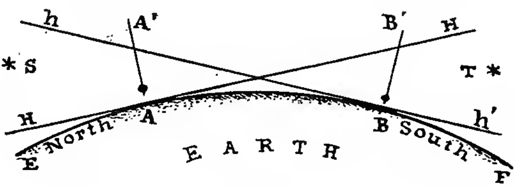


Fig. 8.

Then *EF* is a section of the earth's surface; *HH′*, the tangent line at *A* to the circle *EF*, is a section of *A's* horizon; and similarly *hh′* is a section of *B's* horizon.

Also *AA′* represents the plumb-line at *A*, and *BB′* the plumb-line at *B*. Then *AA′* points to *A's* zenith, and *BB′* to *B's* zenith.

A can see the star at *S* but not at *T*, as *S* is above *A's* horizon, and *T* is below it. And for similar reasons *B* can see the star at *T* but not the one at *S*.

If *A* passes southward to *B*, his horizon gradually rises above *S* and sinks below *T*; or as it appears to *A*, during the journey, *T* rises above the southern line of his horizon, while *S* sinks below the northern line. And here we have a full

explanation why old and familiar stars gradually sink down and disappear and new ones come into view in the opposite part of the heavens when an observer travels from North to South, or South to North. The changes here described as taking place constitute another proof that the earth is approximately spherical.

The *Horizon* is divided into four equal parts by the four cardinal points of the compass, North, East, South and West. Each of these parts is again divided into 8 equal parts, giving in all the 32 points of the mariner's compass. The names of these points, starting from the north, are:—North, north by east, north north-east, northeast by north, northeast, northeast by east, east northeast, east by north, east, east by south, east southeast, southeast by east, southeast, southeast by south, south southeast, south by east, south, south by west, south southwest, southwest by south, southwest, southwest by west, west southwest, west by south, west, west by north, west northwest, northwest by west, northwest, northwest by north, north northwest, north by west, north.

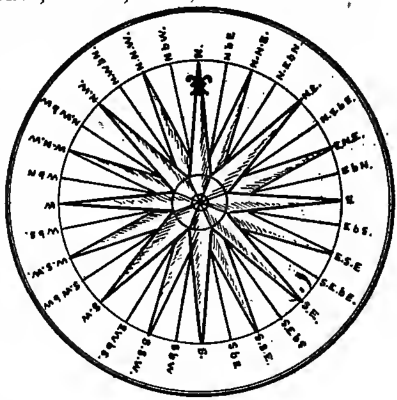


Fig. 9.

The mariner then divdies each of these 32 points into four equal parts called quarter points, thus making 128 quarter points in the circle of 360°, so that the value of a quarter point is 2° 48′ 45″.

A better way of expressing direction on the earth's surface is the one followed by the surveyor and the astronomer, in which all directions are referred at once to one of the cardinal points. Thus, north northeast is expressed as north 22° 30′ east or N. 22° 30′ E., or E. 67° 30′ N.; and S. 27 10′

W. means a direction which makes the angle 27° 10′ west of the south meridian.

Equator and Poles of the Sphere. The section of a sphere by a plane which passes through its centre is called a *great circle* of the sphere. On the surface of the sphere there are two points which are equidistant from all points on this circle. These points are called the *poles* of the great circle, and the circle itself is called the *equator* to these poles or points. This use of the terms poles and equator is a generic one, and is not to be confounded with the particular meanings when applied to the earth.

It is evident that the line joining two points as poles is perpendicular to the plane of their equator.

The zenith and nadir are the two poles of the horizon, and the horizon is the equator to the zenith and nadir considered as poles.

3. Altitude and Azimuth, Vertical Circles, Etc.

In the accompanying figure *Z* is the zenith, *NESW* is the celestial horizon, and the earth is at the centre *O*. *N*, *W*, *E*, and *S* are the cardinal points of the compass.

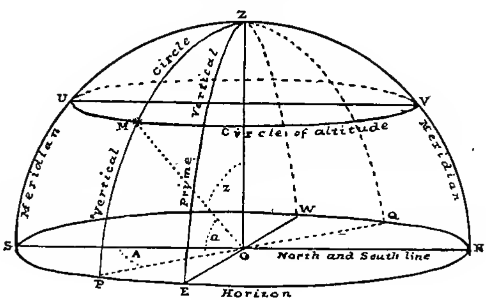


Fig. 10.

Circles such as *EZW*, *PZQ*, etc., which pass through *Z* and meet the horizon in opposite points are called *Vertical Circles,* being great circles which rise vertically from the

horizon to the zenith. As P and Q may be any pair of opposite points on the horizon, the number of vertical circles is unlimited, but certain ones have special names. Thus the vertical circle passing through the east and west points of the horizon, E and W, is called the *prime* vertical; and the one passing through the north and south points of the horizon, N and S, is the *meridian* of the place having Z as its zenith.

The projection of this upon the earth, that is, the line running north and south upon the earth's surface, is spoken of as the meridian line, or *north and south line*.

If a long suspended plumb-line be viewed from a little distance, its projection upon the sky represents part of a vertical circle.

And this method of getting the projection of the pole star upon the horizon, or in fact of any other star of not very high altitude, is sometimes practically employed.

The small circle, UMV, parallel to the horizon, is a *circle of altitude* or an *almucantur.*

If M be a heavenly body, as a star, the angle ZOM is the *zenith distance* of the star, and the angle POM is the altitude of the star. And we see that the altitude of a heavenly body is the complement of its zenith distance; so that if these angles are denoted by a and z, respectively, we have $a+z=90°$.

The angle SOP, between the plane of SZO and the plane of PZO, is the azimuth of M. In this case the azimuth is reckoned from the south, but it may equally well be reckoned from any one of the cardinal points. As the sun rises daily at the eastern horizon and sets at the western one, the sun's altitude is continually changing during his apparent diurnal motion, and the measuring of the sun's altitude at some particular time in the day is one of the commonest observation problems in navigation. In like manner the sun's azimuth changes continually throughout the day.

4. The Altazimuth.

We speak of the horizon, of the meridian, of a vertical circle, etc., as if they were real lines drawn upon the surface of the heavens, whereas such lines have existence only in

theory. It is doubtful, however, if real lines, even if they did exist, would not be more objectionable than useful, for we can, by means of proper instruments, place upon the surface of the heavens any of these lines, whenever and wherever we please. How this is done we proceed to explain.

But, being interested in geometric principles which underlie the action of instruments rather than in their manufacture and sale, we shall use diagrammatic illustrations instead of realistic ones.

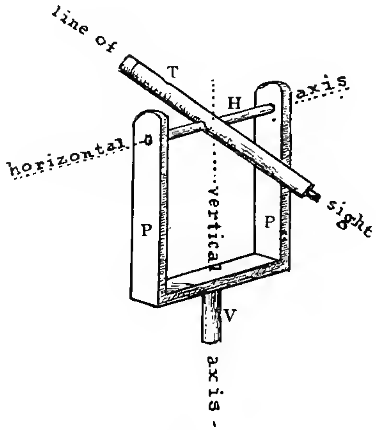


Fig. 11.

T is a telescope whose line of sight is fixed at right angles to a horizontal axis *H*, about which it can be rotated. This axis rests upon two supports *P*, *P* which are firmly connected to the vertical axis *V*, around which the whole can be rotated.

Thus the line of sight of the telescope is perpendicular to the horizontal axis, and the horizontal axis is perpendicular to the vertical one. And it is easily seen that by rotation about these two axes the telescope may be directed to any point in the visible heavens.

If the telescope be pointed to the zenith it will be in line with, or parallel to, the vertical axis, and will continue to point to the zenith while being rotated about the vertical axis. If the telescope be placed at right angles to the vertical axis and the whole be rotated about the vertical axis, the line of sight will trace out the horizon.

If the telescope be directed to an object M in the heavens and be then rotated on the vertical axis, the line of sight will trace out the circle of altitude or *almucantur* MM' on which the object M lies. And finally if the telescope be turned about the horizontal axis only, its line of sight will trace out a vertical circle.

The field of view of the telescope appears as a circle crossed by two spider lines, technically called threads or wires, at right angles, one being vertical and the other horizontal, and the line of sight passes through their point of intersection. So when a star is brought to this intersection the two lines, projected upon the sphere of the heavens, give small portions of the vertical circle passing through the star, and a tangent to the circle of altitude at that point upon it where the star is situated.

This instrument is called an *altazimuth*, because it gives the means of measuring at once the altitude and the azimuth of any heavenly body, or of any elevated point or object required.

5. Earth's Axial Rotation.

As the earth is a spherical body posited in space, it is altogether probable that it is in motion, and the following observations and considerations strengthen this probability.

As has been already pointed out, the relative positions of the stars are the same from year to year, so that if the stars move materially they must move as a whole, and not individually.

Upon any starlit night, preferably when the moon is absent, let one take up a position in which he can command a fairly unobstructed view of the horizon, and let him direct his view, at first, to the northern sky. We will suppose that he is at latitude 45° north.

He will observe about half-way between the north point of the horizon and the zenith, a fairly bright star which stands pretty much alone, having no equally bright stars within some distance of it, and in line with the two stars, in Ursa Major, known as the pointers. This is *Polaris,* or the *north star* or the *pole star.*

Our observer, by continuing his observations for several hours, will notice that all the stars of the northern sky appear to move in circles having Polaris near the centre, the direction of motion being opposite to that of the hands of his watch.

Those stars at the proper distance from the pole, in this case 45°, as represented by the circle *A,* will graze the northern horizon at *N* at their lowest point, and will pass through the zenith, *Z*, at their highest.

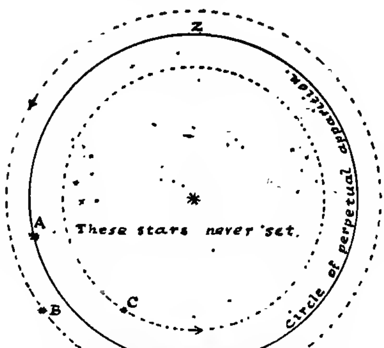


Fig. 12.

Stars represented by the circle *B*, more distant than *A* is, dip below the horizon in the lower part of their course, pass south of the zenith in the upper part, and like the sun and moon regularly rise and set.

But stars at less than 45° from the pole, as represented by the circle *C,* never reach the horizon and therefore never set,

and can be seen, by means of a telescope, at any time when the northern sky is unclouded. Hence the circle *A* is called the *Circle of Perpetual Apparition.*

Of the stars which rise and set, those which rise near the east point of the horizon remain about 12 hours above the horizon and set near its west point; those which rise south of east remain less than 12 hours above the horizon and set south of west. And the farther south a star rises, the farther south it sets and the shorter time it remains above the horison. And these observations are for 45° north latitude, or for an observer situated half-way between the earth's equator and its north pole.

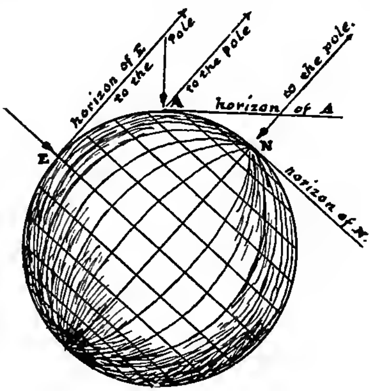


Fig. 13.

If the observer goes southward the pole star descends towards the north point of the horizon, and the circle of perpetual apparition gets smaller, no longer reaching to the zenith; and if he goes northward the opposite change takes place, that is, the pole star rises and the circle of perpetual apparition grows larger and includes a greater number of stars. Altogether similar phenomena would be observed by a person living south of the equator.

To an observer on the equator, *E,* the pole star is on the horizon, and there is no circle of perpetual apparition, or in

other words, this circle is reduced to the pole itself, and all the stars regularly rise and set.

And to an observer at the north pole of the earth, N, the pole is at the zenith, and the circle of perpetual apparition takes in the whole of the visible heavens, and the stars neither rise nor set but travel around in circles parallel to the horizon.

We see from this that the character of the apparent motions of the stars is to some extent dependent upon the position of the observer.

In order to explain these apparent motions, the ancient astronomers supposed that the stars were equally distant from the earth, which was the centre of the universe, and that they were fixed upon some kind of a transparent crystalline shell which daily rotated about an axis pointing to the north pole of the heavens, for, as we shall see hereafter, the present pole star was not the pole star in their days.

But it then became necessary to have other shells or hollow spheres to carry the sun, the moon, and each individual planet, for these all have their own distinct apparent motions. The motion of these shells on their several axes was supposed to grind out a sort of inaudible but philosophic sound known as the music of the spheres.

Such a cumbrous explanation for such simple phenomena is, of course, illogical, and as the stars are not all at the same distance and cannot all be carried on even a thousand revolving shells, the explanation is absurd. Besides, the simple hypothesis that the earth rotates every 24 hours about a central axis which points to the north pole of the heavens explains fully not only all the phenomena described, but also much more that has not as yet been referred to.

These considerations compel us to adopt the hypothesis that the apparent daily revolution of the sun, the moon, and the stars is due to a real rotation of the earth about its own axis. Northwards this axis is directed to a point in the heavens only a little more than one degree from the star Polaris. The miller's objection, that if the earth turns

around the water would be spilt out of his mill-pond, is left to be answered by the reader.

When one pole, *N*, is elevated above the horizon, the

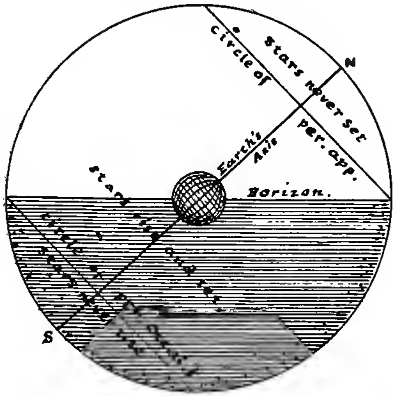


Fig. 14.

opposite pole, *S*, is depressed to an equal distance below the horizon.

> " One pole rides high, one sunk beneath the main
> Seeks the dark night and Pluto's dusky reign."

So that corresponding to the circle of perpetual apparition, in which the stars never set, there is an opposite circle of equal dimensions in which the stars never rise. This is called the *Circle of Perpetual Occultation.*

Only those living on the equator are in a position to see all the stars from pole to pole.

We have a number of direct proofs of the rotation of the earth about its axis, but we shall at present content ourselves with explaining a very important one known as *Foucault's Pendulum Proof.* It is a well-established principle in Physics that when a heavy ball suspended by a cord or wire is set to oscillate in any given plane, it will continue to oscillate in that plane until turned out of it by some extraneous force. But if the weight is suspended by a uniform cord or wire,

and is well protected from air currents, there is no extraneous force to act upon it.

For the sake of easy explanation, let us suppose that the pendulum *CW* is suspended from *C*, a point directly above the north pole, *N*, of the earth, and that *XY* is a small portion of the earth's surface about the pole. Let the pendulum be started to swing along a line *ANB* drawn on the surface *XY*. After some little time, an hour say, it will be seen that the plane of oscillation has apparently shifted from the line *ANB* to a new line *aNb*, the angle *BNb* being about 15°. This may be accounted for by supposing that the plane of oscillation has shifted through 15° in the direction of the movement of the hands of a watch, or by supposing that the surface *XY* has shifted 15° in the opposite direction. But as the plane of oscillation is invariable, the surface *XY*, and therefore the earth itself, must rotate in a direction opposite that of the hands of a watch, as indicated by the arrows.

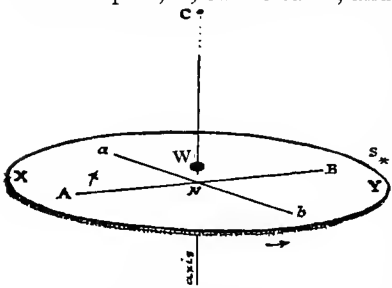


Fig. 15.

Theory tells us that on the equator there is no apparent rotation of the plane of oscillation; at places north of the equator the apparent rotation is right-hand, and at places south of the equator it is left-hand, and also that the rate of rotation increases as you pass from the equator towards either pole. And the theory has been verified wherever and whenever the experiment has been conducted. And thus we have a most convincing visible proof of the earth's rotation on its axis.

Other experimental or mechanical proofs are furnished by (*a*) dropping a ball from the top of a tall tower, when the ball invariably deviates to the east of the vertical; (*b*) the creeping of the rails upon a railway running north and

south; (c) the almost invariable direction of the trade winds, which direction is due to the northerly or southerly course of the wind compounded with the easterly rotational movement of the earth's surface.

6. Terrestrial and Celestial corresponding points and lines.

The distinctive points upon the earth are the north terrestrial pole and the south terrestrial pole, these being the points where the axis meets the surface.

The distinctive circles are: The equator, which lies halfway between the poles; the meridians, which are great circles passing through the poles and crossing the equator at right angles; and the circles of latitude, or parallels of latitude as they are commonly called, which are small circles parallel to the equator.

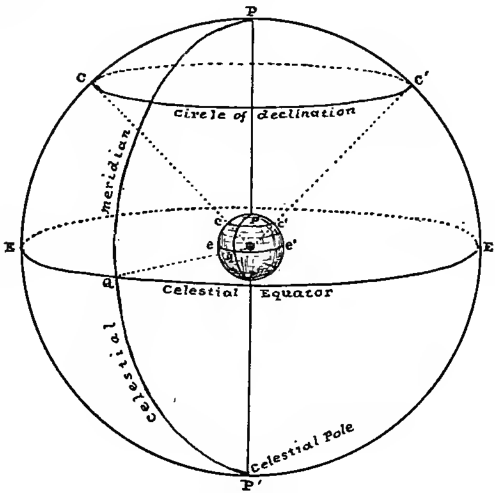


Fig. 16.

Now, from O, the centre of the earth, let the foregoing points and lines be projected upon the sphere of the heavens. The projection gives us the following: (1) The poles of the earth, p, p' become the celestial poles, or poles of the heavens,

P, P'; (2) the terrestrial equator, ee', becomes the celestial equator EE'; (3) a meridian, pqp', becomes the celestial meridian, PQP'; and (4) the circle of latitude, cc', becomes the circle of declination CC'. And thus the points and circles on the celestial sphere are projections, and therefore enlarged copies of those upon the earth.

But as the terrestrial and celestial meridians are supposed to be fixed, each on their own sphere, and as the earth rotates within the sphere of the heavens, it follows that no one meridian on the earth can be said to correspond to any particular meridian in the heavens. In fact, any one terrestrial meridian passes under all the celestial meridians in a trifle less than 24 hours.

Also, if the earth should by any means shift the direction of its axis, the whole enumerated set of celestial points and circles would be correspondingly shifted amongst the stars. We shall see hereafter that such a shifting is going on, although very slowly.

7. Local Meridian.

The celestial meridian which passes through the zenith of a place passes also through the north and south points of the horizon, and is called the meridian of the place, or the *local meridian*. As this meridian is fixed in regard to the earth, it rotates with the earth and passes every star in one revolution of the earth, the apparent phenomena being, however, that the stars, in their diurnal rotation, pass this meridian.

When any celestial body is on the local meridian it is said to *culminate*, and the culmination of sun, moon, and stars are matters of daily observation in every astronomical observatory.

Culmination is usually observed by means of an instrument called a *transit,* which is an altazimuth having no vertical axis, and accurately adjusted to trace out the meridian only, by rotation on its horizontal axis.

The culmination of a body is also spoken of as its *meridian transit.*

8. Latitude and Declination.

The angular distance of any place on the earth from the terrestrial equator is the *latitude* of the place, and is said to be north or south (N. or S.) according as the place is north or south of the equator. Thus the latitude of Kingston is 44° 13′ N.

Similarly the angular distance of a heavenly body from the celestial equator is called the *declination* of the body, and it is north or south according as the body is north or south of the equator. And thus declination in the heavens corresponds to latitude upon the earth. Astronomical latitude has a different meaning, and has no real correspondent in terrestrial relations.

If we were at the equator, the north pole of the heavens would be at the horizon at its north point N. As we went northward the pole would rise; and if we could get to the north pole of the earth our latitude would be 90°N., and the north pole of the heavens would be at our zenith. So that the altitude of the celestial north pole above our horizon measures our latitude north.

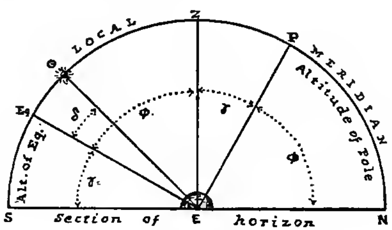


Fig. 17.

Similarly the altitude of the south pole of the heavens gives the latitude of the place south.

In the figure E is the earth, Z the zenith of an observer, SZN is the local meridian, SEN a section of the horizon, P the north pole of the heavens, and Eq the position of the celestial equator where it crosses the local meridian.

Then, as EZ is perpendicular to EN, and EEq is perpendicular to EP, it follows that the angle NEP = the angle $ZEEq$, and the angle ZEP=the angle $SEEq$.

But NEP is the altitude of the pole and $ZEEq$ is the zenith distance of the equator. Hence the latitude of any place on the earth is the same as the altitude of the pole, or the zenith distance of the equator, as measured at the place.

And the co-latitude of a place is the same as the zenith distance of the pole, or the altitude of the equator as observed at the place.

Again, if $\odot$ denotes the sun when on the local meridian, the angle $\odot EEq$ is the sun's declination, and if we denote the angle $\odot ES$, which is the sun's altitude when on the meridian, by a, we readily see that $a=\gamma+\delta=90°-\phi+\delta$.

$$\text{Whence } \phi=90°+\delta-a$$

where ϕ is the latitude, δ is the sun's declination, and a is the sun's meridian altitude.

Thus we can find our latitude upon the earth, by finding the altitude of the pole, or of the sun on the meridian, if we

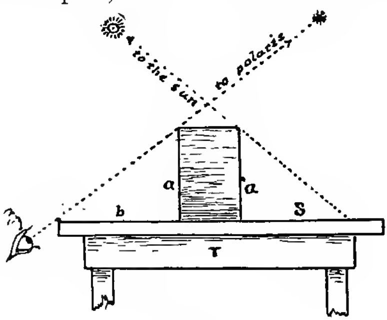


Fig. 18.

know the sun's declination, and this is given in the Nautical Almanac for every day in the year.

The following experimental observation may be carried out by the beginner:

T is a table which is placed with its longer edge as nearly north and south as can be arranged, and is then carefully

leveled. *B* is a box, with right-angled corners, so placed upon the table that its horizontal edges are parallel with those of the table. By placing one's eye, *E*, in the proper position the edges of the table and the box may be brought in line with Polaris, *P*, by moving the box on the table.

Then, carefully measuring the lengths *a* and *b,* we have a/b=the tangent of the altitude of Polaris; and this angle, taken from a table of natural tangents, is the altitude of Polaris and approximately the latitude.

Thus if $a=12$ in. and $b=15$ in., tangent of altitude of Polaris=0.8, the altitude itself is 38° 40′; and this is approximately the latitude.

As Polaris is not at the pole but about 1° 20′ away, it revolves around the pole and has the same altitude as the pole, as at *A* and *A′*, twice in each revolution. But at these times the star is changing its altitude most rapidly, and a failure to get the observation at the right time would produce the maximum of error. At *B* and *B′*, on the other hand, the star is directly above or below the pole and has its altitude practically constant for a short time, so that an error in the time of observation would give a minimum error in the result. At *B* the distance of Polaris from the pole must be subtracted from the observed altitude of Polaris to give the latitude, and at *B′*, it must be added.

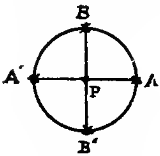


Fig. 19.

The accompanying table gives approximately the times when Polaris will have the position *B* above the pole. The position *B′* below the pole is 12 hours earlier or later on the same date.

Hour	Date	Hour	Date	Hour	Date	Hour	Date
Noon,	Apr. 10	7 p.m.	Dec. 25	2 a.m.	Sept. 10	9 a.m.	May 25
1 p.m.	Mar. 25	8 p.m.	Dec. 10	3 a.m.	Aug. 25	10 a.m.	May 10
2 p.m.	Mar. 10	9 p.m.	Nov. 25	4 a.m.	Aug. 10	11 a.m.	Apr. 25
3 p.m.	Feb. 25	10 p.m.	Nov. 10	5 a.m.	July 25	Noon	Apr. 10
4 p.m.	Feb. 10	11 p.m.	Oct. 25	6 a.m.	July 10		
5 p.m.	Jan. 25	Midn't,	Oct. 10	7 a.m.	June 25		
6 p.m.	Jan. 10	1 a.m.	Sept. 25	8 a.m.	June 10		

The latitude may also be found from the sun's altitude when on the meridian. In figure 18, if S be the length of the shadow cast by the box B, a/S is the tangent of the angle of the sun's altitude. Thence we have

Latitude$=90°+$ sun's declination—sun's altitude.

The declination is positive when the sun is north of the equator, that is, from March 20th to Sept. 23rd, and it is negative during the other half of the year.

9. Longitude and Right Ascension.

A meridian is counted as extending only from pole to pole, instead of completely around the earth, and thus every place has its own meridian, that is, the meridian passing through it.

The angle between the plane of this meridian and the plane of some other meridian, taken as a first meridian, is the longitude of the place.

For geographical purposes longitude is frequently measured east and west from the first meridian up to 180°, but it is better and more in accordance with astronomical usage to express it in time instead of in angle.

As the earth rotates through 360° in 24 hrs. we have 15° is equivalent to 1 hr., 15′ to 1 m., and 15″ to 1s.

Hence the following rule for changing angle into time:

Divide the $\left|\begin{matrix} ° \\ ' \\ '' \end{matrix}\right|$ by 15; call the quotients $\left|\begin{matrix} \text{hr.} \\ \text{min.} \\ \text{sec.} \end{matrix}\right|$

Multiply the remainder from the division of $\left|\begin{matrix} ° \\ ' \end{matrix}\right|$ by 4, and call the products $\left|\begin{matrix} \text{min.} \\ \text{sec.} \end{matrix}\right|$. Add results.

Example. To change 76° 28′ 52″ to time:

Dividing by 15,	5h.	1m.	3s.
With remainders	1	13	7
Multiply by 4		4m.	52s. $^{28}/_{60}$s. or 0.47 nearly.

Sum$=5^h\ 5^m\ 55^s.47$.

To change time into angle, multiply h. m. s. each by 15 and call the products ° ′ ″, and reduce.

Example. To express $5^h\ 5^m\ 55^s.47$ in angle:

Multiplying by 15, $75°\ 75'\ 832''.05$,

And reducing gives $76°\ 28'\ 52''.05$.

The advantage of expressing the longitude of a place in time instead of in angle is apparent from the fact that the longitude expressed in time tells us at once how much the local time of the place is behind that of the first meridian.

Thus, if the longitude of a place be $8^h\ 20^m$, then the time at the place is $8^h\ 20^m$ slower than at the first meridian; so that if the time at the first meridian is $10^h\ 50^m$ a.m., the time at the given place is $2^h\ 30^m$ a.m.

Taking the meridian of Greenwich as the first meridian, the longitude of Kingston is $5^h\ 5^m\ 55^s.5$, which is equivalent to saying that the local time at Kingston is $5^h\ 5^m\ 55^s.5$ behind the local time at Greenwich.

In the ephemeris the times for the occurrence of many phenomena are given for the first meridian only, and from these the times of occurrence at any given meridian are to be found by correcting for the longitude of that meridian.

Just as every place on the earth has its own terrestrial meridian, so every celestial body, as the moon, or a star, has its own meridian in the heavens, and the angle between the plane of this meridian and the plane of some other meridian, taken as a first meridian, is called the *Right Ascension* of the heavenly body.

Right ascension is always expressed in time, unless under particular circumstances, and is measured from west to east around the circuit of the heavens, or from 0 hrs. to 24 hrs.

We have then the correspondences:

Terrestrial.	*Celestial.*
Latitude	Declination
Longitude	Right Ascension.

10. First Meridian.

The equator is a natural line or circle from which to measure latitudes, but there is nothing of that kind amongst terrestrial meridians. so that the choice of a first meridian must be more or less arbitrary.

As a matter of convenience it is easily seen that the first meridian should pass through some large and old-established astronomical observatory. As a consequence, nearly every nation that possesses a national observatory is to some extent jealous of its honor, and wishes to take the meridian of that observatory as the first meridian.

All British subjects adopt the meridian of Greenwich, near London, while the French prefer that of their observatory at Paris, and the Russians that of St. Petersburg. The Americans very commonly follow the usage of Great Britain, although using also the meridian of the Naval Observatory at Washington.

The matter is somewhat confusing, and the giving of the longitude of a place has no meaning until the position of the adopted first meridian is known.

In this work the meridian of Greenwich is taken as the first meridian and the origin of time and longitude.

There is no such difficulty in fixing upon a first meridian in the heavens, as national jealousy does not reach that far, and there are four quite distinctive meridians.

The one adopted as the first celestial meridian cuts the equator where the sun crosses it when coming north in the spring. This point on the celestial equator is called, symbolically, the *first point of Aries,* because it is the point and time at which the sun, in its apparent annual journey, enters the Constellation Aries. It is also called the *ascending node* (nodus, a knot), because it is the place where the sun appears to pass from the south side of the equator to the north side. And as astronomy originated, as far as we know, in the northern hemisphere, it is natural to call that hemisphere the upper one.

This point is also called the *vernal equinox,* as spring begins when the sun reaches this point, and the days and nights are equal in length.

The sun is at the vernal equinox about March 20th.

11. Registration.

A place on the earth's surface is registered by giving its longitude and its latitude, for these being given the position

of the place is known, as no two places can have the same longitude and the same latitude.

In a similar manner a heavenly body is registered by giving its right ascension and its declination.

Star catalogues are catalogues giving these elements for large numbers of stars, sometimes rising into the thousands. In the British ephemeris, as in some other astronomical almanacs, the right ascensions and declinations of the sun and the planets are given for every day in the year at noon, and for the moon they are given for every hour. And in this way we keep account of the positions and motions of these bodies.

12. Wanderings of the Pole.

With the very accurate means of measurement possessed by present-day astronomers, it has been lately discovered that the latitude of a place, contrary to all previous expectations, is not an absolutely fixed quantity, but undergoes some variation, which, although very small, appears to be continuous and very irregular. And two places, like Berlin and Honolulu, which are both in north latitude and about 12 hours apart, possess the correlative property that when the latitude of the one increases, that of the other decreases by the same amount.

As latitude is measured from the equator, it follows that the equator and therefore the poles must shift in regard to the body of the earth. As far as is known, however, the greatest movement of the pole is not more than about 60 feet from the mean position, and this is about one-half second of angle as seen from the earth's centre.

The cause of this wandering of the pole is not certainly known. But the inequality of precipitation of rain and snow upon different parts of the earth, as also the irregular rising and falling of different sea coasts might well be cause enough.

13. The Equatorial

Just as the altazimuth by motions about its two axes traces out vertical circles and circles of altitude, so the equatorial

by motions around its two axes traces out meridians and circles of declination. The construction of the two instruments is much alike, with variations for convenience, but the axis which in the altazimuth is vertical and directed to the zenith, is, in the equatorial, parallel to the earth's axis, and therefore directed to the pole of the heavens.

By means of graduated circles the instrument may be set to any readings in right ascension and declination, and thus its line of sight directed to any star or point in the visible heavens.

14. Dimension and Form of the Earth.

If the earth were motionless and alone in space it would undoubtedly take the form of a sphere, as that is the only form in which the attractions would be all satisfied.

But the sun attracts the earth, and as the attraction is greater upon the side nearer the sun than upon that farther away, this attraction tends to elongate the earth along the line of attraction. The moon exerts a similar effect; and although the resulting effect upon the form of the earth is exceedingly minute, cases will arise in which it must be considered (tides).

But the earth is not motionless, but rotates about its axis. And this brings in centrifugal force, especially about the equatorial parts, and this tends to bulge out these parts and to contract the length of the axis form pole to pole, that is, it tends to give to the earth the form of an oblate spheroid.

It is evident, then, that to find the exact dimensions and the true form of the earth is not a very simple problem.

The deviation from the spherical form is small, however, and for a first approximation to its radius we may quite safely assume the earth to be a sphere.

15. The formula $s=r\theta$.

In this well-known trigonometrical formula, which we shall have occasion to use quite frequently, s denotes the length of an arc of a circle, in any convenient length-unit; θ is the radian measure that this arc subtends at the centre; and r is the radius of the circle; and in this formula these

are so connected that if any two are given the third can be found.

Let Z and Z' be the zeniths of two places A and B situated on the same meridian. Then if ZA and $Z'B$ be produced downwards they will meet at the centre of the circle of which the meridian AB is a part. Let S be a star at its culmination. The angle ZAS is the zenith-distance of the star as seen from A, and $Z'BS$ is the zenith-distance as seen from B, and these two angles are got by observation on S when on the meridian.

Then it is easily seen that the difference of these zenith-distances is the angle at C, or θ.

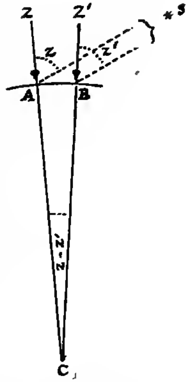


Fig. 20.

The next thing is to measure the arc AB. This is usually done on some extensive tract of level country, and every known refinement in the process of length measurement is employed. This measure gives the value of s, and thence r is found.

For a mean value it is necessary to choose the places A and B at mean latitudes, as the extremes of radii are at the equator and the pole.

16. The Earth's Radius.

Taking now a practical case: In England at latitude about 52°N. it was found that a distance of 364,971 feet subtended an angle of 1°, or $\pi/180$ radians.

Then $r = 364971 \times 180/\pi = 20911300$ feet $= 3960.4$ miles.

And 3960 miles may be taken as a close approximation to the earth's mean radius.

This value for the radius of a spherical earth gives the following results:

Length of the equator, 24884 miles.
Length of 1° in latitude, 69.1 miles.
Length of 1′ in latitude, 1.517 miles, or 6081 feet.
Length of 1″ in latitude, 101 feet very nearly.

This gives for the velocity of a point on the equator, owing to the axial rotation of the earth, about 1040 miles an hour, or over 17 miles a minute.

But how do we know that the earth is an oblate spheroid and not a sphere, for as yet we have had only theory?

17. A Spheroidal Earth.

Measurements of arcs, by measuring rods and triangulation, have been carried out in many parts of the world and in different latitudes, and in the following table we have some of the results:

Country.	Latitude.	Feet in 1° of lat.
Peru	1° 31′S.	362808
India	16° 18′N.	363004
America	39° 12′N.	363786
France	44° 51′N.	364535
England	52° 35′N.	364971
Sweden	66° 20′N.	365782

This table shows clearly that for a given constant angle, 1°, the length of the arc increases as we go from the equator towards the pole. And considering the arcs as small parts of circles, we see that near the pole the meridian belongs to a greater circle than when near the equator, or, in other words, the meridian is less curved at the pole than at the equator.

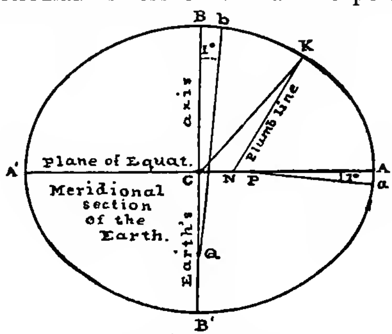


Fig. 21.

Let $ABA'B'$ be a section through a meridian of the earth considered as an oblate spheroid. Take B, B' the points of

the shorter axis as the poles, and then A and A', the end-points of the longer axis, will be points on the equator.

Then it is evident that the meridian is less curved at B than at A, as it should be. And if bQ, aP be normals to the meridian at b and a, and be so taken that the angles BQb and APa are equal and each 1° say, then it is evident that the arc Bb at the pole is longer than the arc Aa at the equator; and as a consequence BQ is greater than AP.

If we know Aa and Bb, we can find AP and BQ by the formula $s=r\theta$. And what we wish finally to find are the radii AC and BC, or a and b.

From the table, by interpolation, we find Aa to be 362740 feet, and Bb to be 366410 feet.

Thence we obtain the values of AP and BQ; and finally by means of a property of the ellipse, which cannot well be given in this work, we get

$AC=a=3962.8$ miles,
$BC=b=3949.5$ " ;

and these are respectively the values of the equatorial radius, and of the polar radius of the earth.

This gives a difference of 13.3 miles between the equatorial radius and the polar radius of the earth, or 26.6 miles between the two corresponding diameters.

Now this 26.6 miles is only about one-three-hundredth part of the whole diameter, and this is expressed by saying that the earth's oblateness is one-three-hundredth, or 1/300.

To form a proper conception of this we may represent a meridian of the earth by drawing an ellipse, or oblong circle, having its diameters respectively 6 in. and 6.02 in.; and if such a figure were accurately drawn it would require careful measurement to prove that it was not a circle.

This protuberance of the equatorial parts is a positive proof that the earth rotates on its axis.

This oblateness, small as it is, has some interesting results.

(1) *Two latitudes.* The most important result to be mentioned at present is that every place on the earth, unless it be at a pole or on the equator, has two latitudes. We have defined the latitude of a place as its angular distance from

the plane of the equator. Now in Fig. 21, let K be a place on the meridian. The plumb-line ZK produced downwards does not pass through C, the centre of the earth, but through a point N on the plane of the equator. The definition gives either of the angles KNA or KCA as the latitude of K. But as the altazimuth is adjusted by the level, which is equivalent to the plumb-line, the angle KNA is the one determined by the instrument. This is accordingly called the observed or *apparent latitude*, while the angle KCA is the *geocentric latitude*, or the latitude as seen from the centre of the earth. The difference, the angle CKN, is called the *correction* of the latitude, or the *angle of the vertical*. It will be sufficient here to say that the greatest value of this angle is about 11′ 30″, which occurs at latitudes about 45°. Apparent latitude is always greater than geocentric, except as before mentioned.

(2) As the pole is nearer the centre of the earth than the equator is, attraction is stronger at the pole than at the equator. So that if a body which, by a spring balance, weighs 194 pounds at the equator, be taken northward, it continually increases in weight until the pole is reached, when it weighs 195 pounds.

Also, the time taken by a pendulum of given length to make one oscillation depends upon the pull of gravity upon the bob of the pendulum. And on account of the earth's oblateness a pendulum clock that keeps correct time at the equator would gain about 4½ minutes daily if taken to the pole. As the surface of the sea may be considered as representing the form of the earth, this form might be determined by timing the oscillations of a standard pendulum made at the seashore in different latitudes.

It is interesting to follow the sequence of small effects which result from the revolution of the earth upon its axis. Some of these have been given in what precedes; others will follow in the proper place.

As the oblateness of the earth is so very small it is quite sufficient for general purposes, as has been said before, to regard the earth as a sphere with a radius of 3960 miles; but where accuracy is required the oblateness must be taken into account.

THE MOON.

The moon, as our nearest neighbor and our dependent, and at the same time the heavenly body that ministers to our comfort and enjoyment more than any other celestial body except the sun, should be of sufficient interest to us to merit our next consideration.

Owing to its proximity to the earth, the problem of finding its distance is not a difficult one, and its features are readily and satisfactorily studied by means of even a moderate-sized telescope, an assertion that can be made of no other heavenly body.

It is true that its always presenting the same face to our view is somewhat of a handicap to our knowledge of it, but this peculiarity is not confined to our moon, and there is no reason for believing that the invisible hemisphere is materially different from the visible one.

Before dealing with the problem of finding the moon's distance it is necessary to consider the subject of

18. Parallax.

A person at *A* has in front of him at some distance a telegraph pole *P*, and at a considerably greater distance a picket fence.

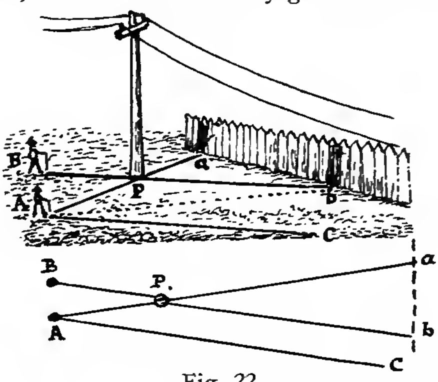


Fig. 22.

He sees the telegraph pole projected on the fence at *a*; that is the pole hides from his view a certain picket at *a*.

The observer now changes his position from A to B, and then sees the pole projected on the fence at b. And thus as the observer changes his position from A to B, the pole is apparently displaced from a to b.

This displacement of the pole is called *parallax*; and we may accordingly define parallax as *an apparent displacement of an object due to a real displacement of the observer.*

The angular displacement of the pole along the fence is the angle aAb, as seen from A. And if the fence were at an infinite distance this angle aAb would become aAC, where AC is parallel to Bb.

In the only cases with which we are concerned, the fence becomes the surface of the heavens with the stars as pickets, and is practically at an infinite distance. So that the angle of parallax becomes the angle $APB=aPb=aAC$, since b and C are coincident at the surface of the heavens.

When the parallax of a celestial body is large the body is relatively near, and when it is small the body is relatively distant, provided the same base, AB, is employed in each case.

The moon has by far the greatest parallax of all the heavenly bodies and is therefore the nearest to us.

Some of the stars have parallaxes of less than 1″ when the diameter of the earth's orbit, a length of over 180 million miles, is taken as a base. And even with this enormous base the majority of the stars have no appreciable parallax.

Limb. When a heavenly body presents a circular disc the edge of the disc is called the *limb,* and different parts of the edge are distinguished by naming them, as the upper limb, the eastern limb, etc. As it is not practicable to observe the centre of the disc, there being no point or mark to distinguish it, observations are made upon the limb intsead. Thus, to find the altitude of the sun, we measure the altitude of its upper limb, and apply a correction for its semi-diameter.

19. Moon's Parallax.

If, when the moon is on the meridian we could suddenly shift our position from one point to another many miles north or south of the former, the displacement of the moon amongst the stars, due to parallax, would be conspicuously

evident. Or, if two observers on the same meridian, and many miles apart, observe the moon when on their common meridian, its position among the stars will not be the same for each observer.

Now, Berlin in Germany, and the Cape of Good Hope are nearly on the same meridian, while one is north of the equator and the other is south, and at each place there is a well-equipped astronomical observatory.

In the diagram B is Berlin, C is the Cape of Good Hope, and M is the moon.

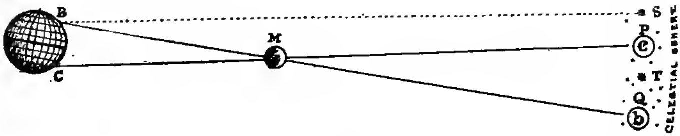


Fig. 23.

The observer at B sees the moon projected amongst the the stars at b, and the observer at C sees it projected at c.

To the observer at B the moon is south of the star T and at a considerable distance from the star S, while to the observer at C the moon is north of the star T and near the star S.

If we can find the parallactic angle BMC and the distance BC as well as the angle MBC, we can calculate the distance MB by simple trigonometry.

But the stars being practically at infinity, we have—

$$BMC = bMc = bBc = \angle QBS - \angle PBS.$$

So that if the observers at BC each measure the angular distance of the star S from the upper or lower limb of the moon, the difference of these measures is the parallactic angle required.

The true place of the moon amongst the stars is its projection as seen from the earth's centre, and this is technically called the *Geocentric* place of the moon. Considering the earth as a sphere, to a person so situated as to have the moon at his zenith, its observed place is also its true or geocentric

place. But as seen from every other point the moon is displaced by parallax, and the displacement increases as the moon gets farther from the observer's zenith. The greatest displacement is when the moon is on the observer's horizon. This is called the *moon's horizontal parallax*, and its average value is a trifle over 57′.

It is readily seen that the moon's horizontal parallax is the angle subtended by the radius of the earth as seen from the moon. Similarly the angle subtended by the earth's radius as seen from the sun is called the sun's horizontal parallax.

An observer upon the earth is carried around by the earth's diurnal rotation, and his position in regard to the moon is continually changing; which means that the moon's parallax, with regard to any one place on the earth, is subject to constant variation, which partly, at least, repeats itself in every lunar day.

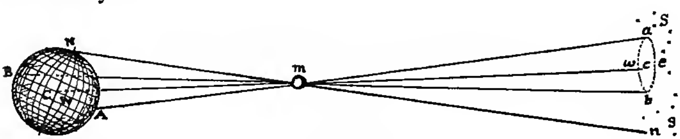


Fig. 24.

Thus if *C* be the centre of the earth, *m* be the moon, not on the celestial equator, and *SS* be the celestial sphere, the geocentric place of the moon is at *c*. To a person situated on the equator, as at *A*, and carried by diurnal rotation along the equatorial circle *AWB*, the moon would appear to move in an ellipse *eawb* having its center at *c*, except that only one-half of this ellipse could be observed.

If the moon were on the celestial equator this ellipse would become a straight line passing through *c*. If the observer moved towards the north pole the ellipse would move southwards and diminish in size; and when the north pole was reached the ellipse would become a point, with a maximum downwards displacement.

All these displacements taken together are sometimes spoken of as the *moon's diurnal parallax*.

When we consider, then, these parallactic displacements of the moon, and bear in mind that the moon is at the same time moving eastwards among the stars, we can understand that the moon's apparent motion in the heavens from the time of its rising to that of its setting is one of considerable complexity.

The moon's true place is independent of the position of the observer, and is recorded in the ephemeris from hour to hour, and its apparent place is to be got by the application of a number of corrections depending upon the latitude of the observer, the moon's declination, its distance from the local meridian, etc.

When the moon is on the horizon its parallax is the horizontal parallax, and when it is at the zenith its parallax is zero.

At any altitude, not 90°, the moon is displaced downward, and this is called the *moon's parallax in altitude*.

20. Moon's distance.

If we could find the moon's horizontal parallax directly by observation, nothing would be easier than to find the moon's distance by application of the formula $s=r\theta$. This might be done under certain special arrangements, but as observatories are situated, not at special, but at convenient points, it is more practicable to follow another course, as follows:

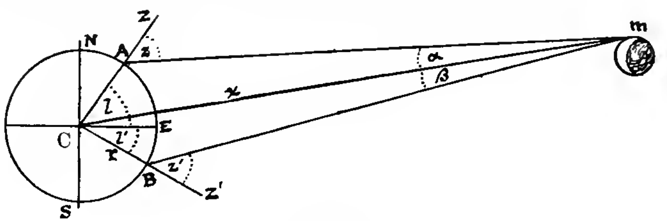


Fig. 25.

C is the earth's centre and *m* is the moon's northern limb, and the problem is to find *Cm*.

Let *A* and *B* be two observers on the same meridian, or nearly so, as at Berlin and the Cape of Good Hope. And let

their latitudes be denoted by l and l'. Then the angle ACB is $l+l'$. The observers measure the zenith distances ZAm and $Z'Bm$ respectively. Denote these by z and z'. Also let r be the radius of the earth, and denote the distance Cm by x, the angle AmC by α, and BmC by β.

From the sine formula of plane trigonometry,

$$\sin\alpha=(r/x)\sin z, \text{ and } \sin\beta=(r/x)\sin z'.$$

$$\therefore\ \sin\alpha+\sin\beta=(r/x)(\sin z+\sin z').$$

But by a well-known formula,

$$\sin\alpha+\sin\beta=2\sin\tfrac{1}{2}(\alpha+\beta)\cos\tfrac{1}{2}(\alpha-\beta).$$

And $\alpha-\beta$ is necessarily a small angle, and $\frac{1}{2}(\alpha-\beta)$ will not exceed $10'$, so that $\cos\frac{1}{2}(\alpha-\beta)=1$ without any appreciable error. Thence by substitution,

$$x=\tfrac{1}{2}r(\sin z+\sin z')/\sin\tfrac{1}{2}(\alpha+\beta).$$

But $ACBM$ is a quadrangle and the sum of its angles is four right angles; and these angles are

$$\alpha+\beta,\ 180°-z,\ 180°-z', \text{ and } l+l'.$$

$$\therefore\ \alpha+\beta=z+z'-l-l'.$$

And finally,

$$x=\tfrac{1}{2}r(\sin z+\sin z')/\sin\tfrac{1}{2}(z+z'-l-l').$$

Illustration. Suppose for illustration that $l=30°$N., $l'=20°$S., and that z and z' are found to be $35°$ and $15°\ 48'$ respectively. Then $\sin z+\sin z'=0.84586$,

$$\sin\tfrac{1}{2}(z+z'-l-l')=\sin 24'=0.00698.$$

$$\text{And } x=\tfrac{1}{2}r\times 0.84586/0.00698=60.6r.$$

This makes the moon's distance from the centre of the earth to be 60.6 times the radius of the earth, or about 240,000 miles if the earth's radius is taken as 3960 miles. And this is about correct.

Spectroscopic illustration. This is an illustration of the effects of parallax. We have two pictures, of two stars and the moon between them, separated by a vertical line. But the moon is represented as being displaced by parallax, with reference to the stars, to the left in the left picture and to the right in the right picture. Consequently the moon should appear nearer than the stars if the left picture is viewed by the

right eye and the right picture by the left eye. And the moon should appear more distant than the stars if the left picture be viewed by the left eye and the right by the right eye.

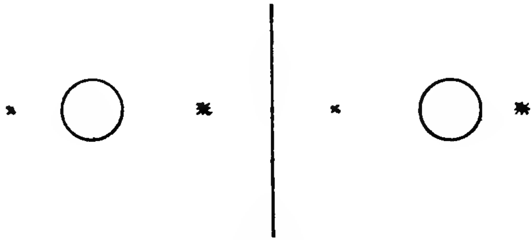


Fig. 26.

To view the pictures properly, (1) cut a rectangular hole about 1 in. by $\frac{3}{4}$ in. through a piece of cardboard. Hold the page fairly before the eyes about 12 in. distant, and look at it through the opening in the cardboard, it being about 5 in. in front of the eyes with its longer dimension right and left, and so situated that the left eye can see only the right figure, and the right eye, the left figure. A little practice will unite the figures, when the moon will appear to come forwards and leave the stars in the distance. (2) Cut a slip of cardboard about $1\frac{1}{4}$ in. wide and 4 in. long. Holding the book as before, hold the slip of cardboard with its longer dimension vertical, and in such a position that the right eye can see only the right figure, and the left eye only the left one. Upon now uniting the figures the stars appear to come to the front and leave the moon in the background.

In this illustration the stars become the fence, the moon the telegraph pole, and the eyes become the observers at A and B. In (1) the telegraph pole is in front of the fence, and in (2) behind it.

21. Moon's diameter.

The angle subtended by the disc of the moon, or the moon's angular diameter, is about 31′, and its distance is 240,000 miles.

Hence the moon's diameter $=(31/60)\times 240000\times\pi/180$ $=2160$ miles.

The moon's diameter is thus three-elevenths of that of the earth. And as the volumes of spheres are proportional to the cubes of their diameters we find the volume of the earth to be about 50 times that of the moon.

Variation in moon's distance. The average angular diameter of the moon is about 31′, but this angle is variable, ranging from $29\frac{1}{2}'$ to 33′, as represented in the diagram.

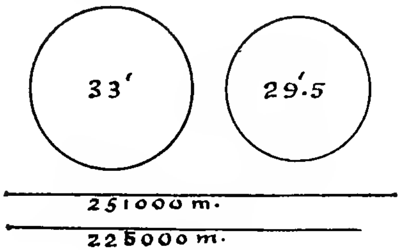


Fig. 27.

Now, as the moon does not change its linear diameter, it must change its distance from the earth; and by the application of the formula $s=r\theta$ we readily find that when the angular diameter is $29\frac{1}{2}'$ the distance is 251,000 miles, and when 33′ the distance is 225,000 miles. These distances are represented by the relative lengths of the lines in the diagram.

The mean of these two extreme distances is 238,000 miles, and this we shall take as the *average* distance of the moon.

The rising and setting of the moon, as of the sun and stars, is due to the rotation of the earth on its axis.

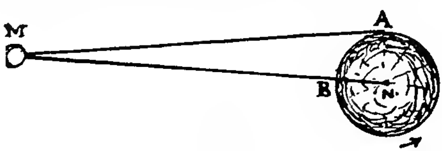


Fig. 28.

22. Moon's diurnal augmentation.

Let N be the north pole of the earth, and M be the moon, and for simplicity of explanation suppose the moon to be on the celestial equator. To the observer at A the moon is on the horizon and is rising. When, by the earth's rotation, the observer comes to B he is nearly 4000 miles nearer to the moon than he was at A, and the moon must appear larger than at A. This increase in the moon's apparent diameter is known as the *moon's diurnal augmentation,* as it is repeated in every lunar day. Its greatest amount is about one-half a minute of angle.

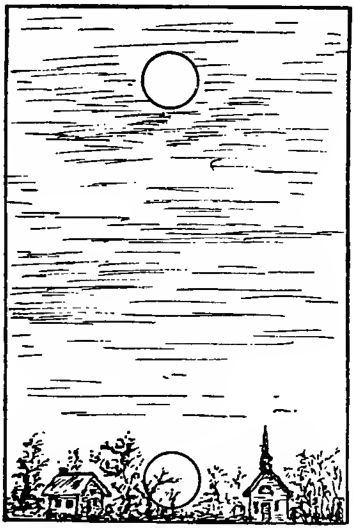


Fig. 29.

To most people the moon appears to be larger when rising and setting than when far up in the heavens. This, however, is an optical illusion arising from the fact that when the moon is on the horizon we have objects such as trees and

buildings with which to compare it, while there are no such objects for comparison when the moon is far up. In like manner the distance across a considerable body of water appears less than the same distance on land where there are various intervening objects.

In the illustration the two circles are exactly of the same size, but upon viewing them carefully the upper circle appears to be the smaller one.

23. Kepler's law, I.

John Kepler lived from 1571 to 1630. By a persistent course of trial, extending over many years, and involving an immense amount of arithmetical computation, he discovered three laws in regard to the motions of planetary bodies; and these go under his name.

Newton was not born until 1642, so that Kepler knew nothing of the law of gravitation as developed by Newton, and yet all his three laws have subsequently, by means of mathematical analysis in the hands of Newton himself, been proved to be correct.

The first law is—All the planets move in ellipses having the sun at a focus.

This may be more fully stated as follows: A body revolving under the pull of a central force whose intensity varies inversely as the square of the distance, describes a conic section with the centre of force as a focus.

For all the planets and satellites the conic is an ellipse, so that, barring disturbing influences, the moon's path is an ellipse with the earth at a focus.

The Ellipse. The ellipse is so common a curve in astronomy that it is impossible to proceed intelligently without knowing some of its more obvious properties.

Put a sheet of white paper on a smooth table and pin it down by two pins S and F.

Make a loop of thread, not too large but so that it will drop over the pins easily. With a pencil, as at P, draw the thread until the loose parts PS, SF, and FP become straight. Under these conditions, the pencil, upon being moved over the paper, will mark out or describe an ellipse.

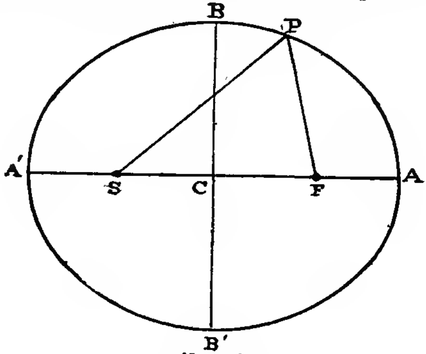


Fig. 30.

The points S and F are the *foci.* The point C, bisecting SF, is the *centre,* and the curve is symmetrical, for opposite points, about the centre. AA', drawn through the foci and centre, is the *axis major*; and BB' drawn through C, perpendicular to AA', is the *axis minor*; and the ratio CF/CA is the *eccentricity.*

With a fixed length of loop it is readily seen that when S and F come near together the ellipse approaches the form of a circle, becoming a circle when S and F are coincident. On the other hand, as S and F get further apart the ellipse tends to become long and narrow, and the eccentricity, which is zero in the circle, approaches unity.

To describe an ellipse which properly represents the form of the moon's orbit we should put the pins 1 unit apart and make the double loop 9.7 units long, or containing 19.4 units of thread, where the unit may be any length unit convenient.

This ellipse will be found to be scarcely distinguishable from a circle, but it is quite readily seen that the earth is not at the centre (Fig. 31).

The point P, where the moon is nearest the earth, is the *perigee,* and when the moon is at this point in its orbit it is said to be in perigee. The opposite point, A, where the moon

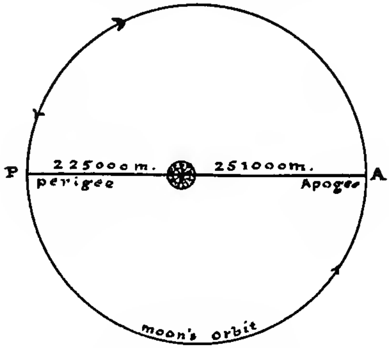


Fig. 31.

is farthest from the earth, is the *apogee.* And the line connecting these points is the *apsis line* or *line of apses.*

24. Mass-centre.

Observations certainly show that the moon appears to revolve about the earth, moving from west to east amongst the stars so as to complete its circuit in a little less than a month, but how do we know that this is not a deceptive appearance arising from the revolution of the earth about the moon? The question is quite a proper one to be answered.

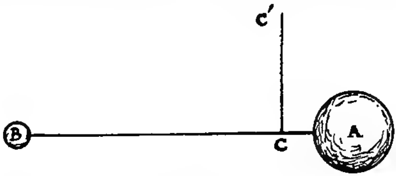


Fig. 32.

A and B are two leaden balls of which A is much larger than B, and they are held together by a rod AB which, for

simplicity of explanation may be supposed to be without weight. A thread, CC', is attached to the point C about which the system balances. By twisting the thread, without otherwise displacing the system, the balls may be made to revolve about one another.

It will be noticed that while the balls travel around in circles, the point C remains still. This point about which the revolutions take place is the *mass centre* or *centre of gravity* of the system. This centre divides the distance between the centres of the balls into parts which are inversely proportional to the weights of the balls. Thus if A is 10 times as heavy as B, C is 10 times as far from the centre of B as it is from the centre of A.

The system described is not like a piece of mechanism. There is nothing to keep C in position or to restrain it from moving from side to side, the only purpose of the thread being to keep the system from obeying the pull of gravity and falling to the floor. If the string were cut while the balls were revolving, their relative motions would not be interfered with in any way, while the point C would move directly along the line of the earth's attraction.

Now various considerations have shown that the earth is about 80 times as heavy as the moon, being apparently formed of denser or more compacted material, so the mass centre of the two bodies is $^1/_{80}$ of 240,000 miles, or 3000 miles from the earth's centre, or at a point 1000 miles below its surface. Generally speaking, then, it would savor of pedantry to say that the moon does not revolve about the earth, but about a point 1000 miles below its surface, although the latter statement would be the correct one. And, in fact, it would be quite right to say that the earth revolves about the moon, if anything in the way of explanation were to be gained thereby, for in either case outside phenomena would be but little, if at all, interfered with.

We see, then, that the path of the earth's centre as it moves along in its orbit about the sun, is not a smooth line or curve, but a wavy one, in which a wave is completed at every revolution of the moon. This throws the centre out

to the extent of nearly 3000 miles, first to one side of the ideal orbit and then to the other, besides alternately retarding and accelerating its motion.

Here, then, is a source of small displacements and disturbances which must be taken into consideration wherever accurate observations and results are concerned. And it is a blessing to the astronomer that the stars are so far away as to suffer no parallax from these numerous small displacements.

25. The Tides.

As has been already pointed out, the attraction of the moon upon the earth tends to elongate the earth in the line of attraction, and so also does the attraction of the sun. But it has been shown in a variety of ways that, while the surface of the earth is largely covered with a light mobile liquid, water, the body of the earth in itself is as rigid as steel. So that while the pull of the moon may affect the whole earth to a very minute extent, it is chiefly expended in raising two heaps of water, one facing the attracting body, and the other upon the opposite side of the earth. These are known as the tides.

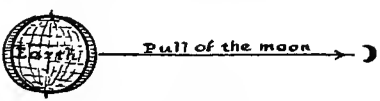


Fig. 33.

On account of the proximity of the moon to the earth the tides due to lunar influence are much greater than those due to solar influence. For the formation of the tides is due not so much to the relative force of the attraction itself, as to the difference of attraction on the opposite sides of the earth, and therefore to the ratio of the earth's diameter to the distance of the attracting body.

As the earth rotates on its axis these heaps of water, tending to keep beneath the moon and also on the side of the earth opposite the moon, sweep over the surface of the sea from east to west, something like two very broad and shallow

waves. They are not, however, properly waves, and do not possess the prominent property of waves, the recurrence after short periods of time.

Upon the open ocean the tides do not rise to a height of more than two or three feet, and instead of being a visible wave with a crest, it is merely a slight elevation of the surface of the sea, which thins out in every direction for hundreds, and possibly for thousands of miles, where the ocean is sufficiently extended.

When this tidal accumulation of water, in its onward progress, encounters some properly disposed shore and is directed into a wedge-shaped estuary, the water may rise from 30 to 60 feet, and rush rapidly for some distance up the channels of properly exposed rivers, thus forming an inrush of water known as the *bore*. These phenomena are to be seen in the Bay of Fundy and the St. John's river, and in fact upon any eastern shore of a continent.

The eastern shore of a continent is met by the tide with full force, while there is no counteracting influence on the western shore, as the tide there is less pronounced, and mostly the result of reflex action. This must act as a sort of break to the earth's rotation and should tend to lengthen the day. But it is generally held that the heaving up of mountain ranges and some other related phenomena are due to a contraction of the earth through a slow loss of its internal heat. This contraction tends to increase the rate of diurnal rotation and thus to shorten the day. These opposite tendencies pretty much annul one another, and it does not appear that the day has changed its length by as much as one second in the last hundred years.

When the sun, moon, and earth are in line the solar tides augment the lunar ones, and we have high tides known as *spring tides*. And when the directions of the sun and moon are at right angles as seen from the earth, the solar tides tend to reduce the lunar ones, and we have low or *neap tides*.

People, like fishermen, who have much to do with the sea notice many peculiarities in the tides. Thus the two tides which occur about 12½ hours apart are usually not of equal

magnitude, the one under the moon being sometimes greater and sometimes less than the tide opposite the moon, the change from greater to less, and back again, taking place in about a month. Of course all these variations are logically explainable. Consider a seaport in north latitude at about 45° say. When the moon is on the equator the two tides will be about of equal size. As the moon goes south from the equator the tide under the moon grows less than the one opposite the moon, and as the moon goes northwards from the equator the opposite effect is produced. And the moon in its orbit crosses the equator twice in each revolution.

To dwellers inland the times of high water are of only secondary importance. But in many seaport towns the arrival and departure of vessels of large size can be safely effected only near the time of high water, and in such places the times of high water are given publicly from day to day.

26. Moon's one face.

Long ago in the past ages of the earth, when the moon was young, it must have been soft and plastic, with more or less liquified matter upon its surface. The attraction of the earth upon the moon under these conditions must have raised immense tides upon the lunar surface, for the power of the earth to raise tides upon the moon is somewhere about 500 times the power of the moon to raise tides upon the earth. These lunar tides acting as a gigantic break upon the axial rotation of the moon has brought it to rest relatively to the earth. So that now the moon rotates on its axis in the same time as it revolves about the earth, and thus presents, practically, always the same face to the earth. And this is the fate, whether as yet realized or not, of every moon which revolves about a planet much larger than itself.

THE SUN.

Astronomical symbol ⊙.

The sun is a fixed star. And although it does not take rank as one of the hottest, or the brightest, or the largest of

the stars of the universe, it is to us the all-important one—the great centre of attraction—the bountiful dispenser of light and heat to every creature which dwells in this solar universe. One of the first questions, then, that we are disposed to ask in regard to this wonderful luminary is as to its distance from us. How far away is the sun?

27. The Sun's distance.

The finding of the distance of the sun is one of the old and difficult problems of astronomy, and it is only in comparatively recent times that any real success has been achieved in its solution. Much of this success has come through channels which were quite unknown to ancient and mediaeval astronomers.

The sun is so far distant and its parallax is accordingly so small that methods like those applied to the moon are quite useless, for the unavoidable errors of observation hold so large a ratio to the whole parallax as to vitiate and render untrustworthy any results arrived at.

As we are not yet prepared to show how the sun's horizontal parallax is found, we shall in the meantime assume its value to be 8″.8, leaving it to a future occasion to show how so small an angle is determined.

As the sun's horizontal parallax is the angle subtended by the earth's radius as seen from the sun, we apply the formula $s=r\theta$ and obtain:

$$3960=D\times 8.8\times\pi/(3600\times 180)$$

whence $D=92{,}900{,}000$ miles, nearly.

And for the average distance of the sun we shall take $D=93{,}000{,}000$ miles.

This is easily shown to be nearly 400 times the distance of the moon.

Owing to these large numbers it is not practicable to draw to scale a diagram or plan representing the system of the sun, the moon, and the earth.

For, if the earth were represented by a small circle one-tenth of an inch in diameter, the moon would be represented by a circle only one thirty-sixth of an inch in diameter, at the distance of three inches from the earth, while the sun would be a circle 10.8 inches in diameter at a distance from the earth of about 98 feet.

These considerations make it clear that diagrams representing astronomical sizes and distances, as they actually appear in illustrated books, however necessary they may be as illustrations, must unavoidably be, at times, exaggerated along certain lines if they are to appear at all.

Thus the figures picturing the comparative sizes of the planets are usually on a scale many times as great as that upon which comparative distances are pictured. And some comparisons of astronomical distances cannot be properly made upon any scale whatever, great or small.

Thus, as the sun is about 400 times as far from the earth as the moon is, if the distance of the moon be represented by one-tenth of an inch the sun's distance would become 40 inches, and that of the most distant planet, Neptune, about 100 feet, measures altogether impracticable in graphic illustration.

28. Sun's Diameter.

Knowing the mean distance of the sun, it is an easy matter to find the sun's angular diameter and then to find its diameter in miles by using the formula $s=r\theta$. For r is 93,000,000 miles, and θ is the radian measure of 32′, which is the mean angular diameter of the sun, and this gives about 850,000 miles for the sun's linear diameter.

This is nearly 108 times the diameter of the earth, so that it would require 108 earths placed side by side to reach across the sun.

As a consequence, to represent truthfully the comparative sizes of the earth and the sun, we may take a small circle one-twelfth of an inch in diameter to represent the earth, and a circle of 10.8 inches in diameter for the sun, as in the diagram, where only a part of the sun's disc is shown.

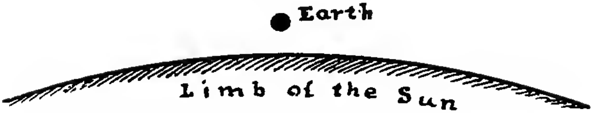


Fig. 34.

29. Volume of the Sun.

As the volumes of the spheres are proportional to the cubes of their diameters, the volume of the sun is $(108)^3 = 1,250,000$ times, nearly, that of the earth; in other words, it would require one and a quarter millions of bodies like this earth to make one body equal in bulk to the sun.

These illustrations show us clearly the insignificance in size of this great round world of ours, where so many things are done, where so many human beings live, and work, and enjoy themselves, and suffer, and die, in comparison with the mighty sun, which warms us, and lights us, and cheers us, and gives us all the material comforts that we possess.

And yet for untold ages people believed that the sun actually performed a daily journey around the earth in order to give us the alternation of day and night. And no doubt a few ignorant people believe it still, in spite of the absurdity of such a view in the presence of the comparative sizes of the two bodies.

However, as explained in connection with the moon, the earth and sun revolve about their common mass centre, which is a point about 300 miles from the centre of the sun, and if explanations are rendered more simple by doing so, there is no objection, but rather an advantage, in considering the sun as travelling around the earth once in a year to bring in the seasons.

Only one view is consistent with the principles of physics, namely, that the bodies revolve about their common mass centre, but which view we adopt as a matter of explanation is in many cases quite immaterial, as all motion is relative, and phenomena are unchanged.

In consideration of these facts, we shall adopt that view which may at the time be most convenient.

30. Sun's angular diameter.

The angular diameter of the sun, like that of the moon, is not constant, but varies from 32′ 36″.4 at its greatest, to 31′ 31″.8 at its least, giving a difference of 1′4″.6.

This shows that the distance of the sun is variable. Working out the greatest and least distances as given by the least and greatest apparent diameters, we get:

Date.	Angular diam.	☉'s distance.
Jan. 1st	32′ 36″.4	91,197,000 miles.
July 1st	31′ 31″.8	94,312,000 "

31. Earth's Orbit.

The earth's orbit is an ellipse, with the sun at one of the foci, thus satisfying the first law of Kepler. The distance of the sun from the centre of the ellipse is about 1,600,000 miles.

The point where the earth is nearest the sun is the *perihelion,* and the point at which it is most distant is the *aphelion.*

At present the earth is in perihelion on Jan. 1st, and in aphelion on July 1st. And thus, strange as it may appear, inhabitants of the northern hemisphere are nearer the sun in the depths of winter than they are in the warmth of summer. For those in the southern hemisphere the case is, of course, just the reverse.

This may have some effect on the seasons in the different hemispheres in the way of making the extremes of temperature in the southern hemisphere somewhat greater than in the northern one, but such effect, if any, does not appear to be very strongly marked.

32. Kepler's law, II.

In orbital motion of one body about another, as the moon about the earth, or the earth about the sun, etc., the line joining the two bodies is called the *radius vector*; and it is a physical principle in astronomy, known as Kepler's second law, that the radius vector sweeps over equal areas in equal times.

Let *ABP* represent the earth's elliptic orbit, necessarily much exaggerated in eccentricity in order to strengthen the illustration, and let *S* be the sun, *P* the perihelion and *A* the aphelion.

Starting from *P*, let the earth arrive at *Q* at the end of one week, say, at *R* at the end of two weeks, at *T* at the end of three weeks, etc. Then Kepler's law II tells us that the sectorial areas *PSQ, QSR, RST,* etc., are all equal.

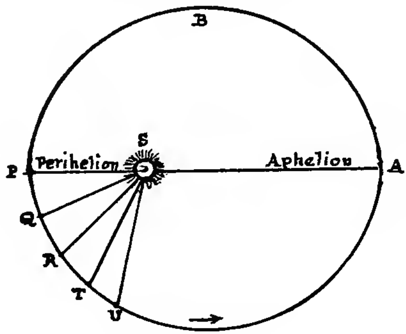


Fig. 35.

But *SP* is less than *SQ*, and *SQ* is less than *SR*, which is again less than *ST*, and each is less than *SA*.

Hence *PQ* is greater than *QR*, *QR* is greater than *RT*, etc.

But as these arcs are each described in the same time of one week, the earth must move more rapidly from *P* to *Q* than from *Q* to *R*, etc. Or, in other words, the earth moves most rapidly at the perihelion *P*, and its motion is gradually retarded until it reaches aphelion at *A*, at which point it moves most slowly. After passing *A* its velocity is gradually accelerated until it arrives at *P* again.

Consistently with this theoretical inference, observations made upon the sun's apparent daily motion along its path in the heavens—that is, the earth's real motion in its orbit—gives 61′ 9″ on January 1st, and 57′ 11″ on July 1st, the mean daily motion for the whole year being 59′ 8″.2.

33. The Ecliptic.

The plane of the earth's orbit, extended out indefinitely, meets the sphere of the heavens in a great circle which is called the *ecliptic*. This plane, and consequently the ecliptic, holds the same position in regard to the stars as a whole, or to the celestial sphere, from year to year and presumably from age to age, as any slight variations in its position appear to be very limited in magnitude, periodic, and more apparent than real.

As a consequence the ecliptic is the one and only fixed and permanent element of reference in astronomy, and all other elements are finally referred to the ecliptic.

The other great circle in the heavens which, for our purposes, is equally as important as the ecliptic, but not equally as fixed, is the celestial equator.

These two great circles intersect at opposite points in the heavens at an angle of 23° 27′, which is known as the *angle of obliquity of the ecliptic*.

The ecliptic and the equator. In representing these circles upon the plane of the paper, as is often necessary, some of them will appear in the diagram as ellipses. And we must assume the impossible condition that we are viewing the universe from some outside standpoint. But these things should not mislead any intelligent reader.

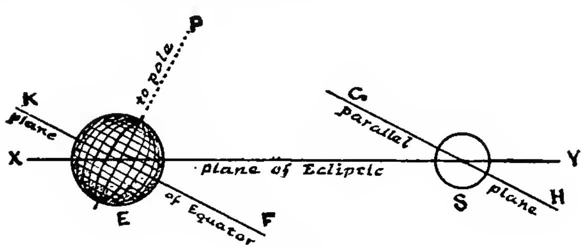


Fig. 36.

Let E be the earth and S the sun, and let the line XY be a section of the plane of the ecliptic, passing, as it does, through the centres of the earth and the sun.

Let KF be a section of the plane of the equator, making the angle $KEX = SEF = 23° 27'$, and if P be in the direction of the celestial pole, making the angle $PES = 66° 33'$, this latter being the inclination of the earth's axis to the ecliptic.

Now let GH be a section of a plane through the sun's centre and parallel to the plane of the equator.

The two planes of which KF and GH are sections meet at the surface of the heavens to form one and the same great circle, the celestial equator. So that as far as the celestial equator is concerned it is immaterial whether we consider the plane of the equator as passing through the centre of the earth, or through that of the sun.

But with the terrestrial equator it is different. For this curve should be the intersection of the surface of the earth by the plane of the celestial equator. So that if we wish to consider this plane as being fixed it is simpler to look upon the earth as being fixed, and the sun as making an annual journey around it in the plane of the ecliptic; and this is the view usually taken in illustrations.

That the phenomena concerned are independent of which view is taken is shown by the fact that the idea of a fixed earth prevailed for thousands of years before the modern and correct state of affairs became known, and yet the same phenomena are present now as then, and have been present during all the past time.

34. Nodes and Solstices.

The diagram (Fig. 37) shows the earth E at the centre, the celestial equator QQ', the poles of the heavens Np, Sp, and the ecliptic Ws, Ss. P is the pole of the ecliptic.

As the ecliptic and the celestial equator are both great circles in the heavens, they intersect in two opposite points A and D on the sphere of the heavens. The sun, S, is represented as moving along the ecliptic, the arrow showing the direction of motion, and it is in the position that it would have about the latter part of February.

The half of the celestial sphere which lies north of the equator is said to be *above* the equator, and the other half *below*. As the sun moves onwards it comes to *A, the ascending node,* about March 20th or 21st. Here it passes from below to above the equator, and hence the name of the node. For the next three months the sun rises higher and higher above the equator until it reaches the highest point, *Ss,* about

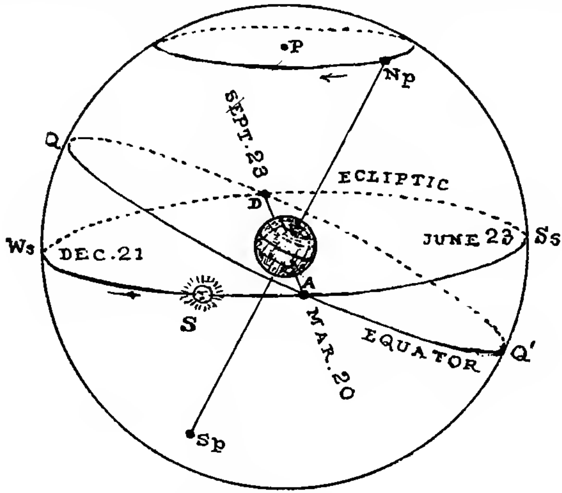


Fig. 37.

June 23rd. This is called the *summer solstice,* because the season of summer begins, and the sun having ceased to rise higher towards the pole, begins to descend. The day is now the longest in the year for those dwelling in the northern hemisphere, and the night is the shortest.

For the next three months the sun gradually works southwards until it reaches the *descending node* on Sept. 22nd or 23rd. Here it crosses from above the equator to below. Working southwards for another three months, the sun arrives at the winter solstice, *Ws,* on Dec. 21st. Winter now begins, and the sun, turning northwards again, arrives in due

time at the point from which it set out, and the circle of the year is complete.

The point A is also called the *vernal equinox,* because when the sun reaches this point spring begins, and the days and nights are of equal length. For similar reasons the point D is called the *autumnal equinox.*

In the next diagram we have the ecliptic as seen from its pole, with the earth at its centre.

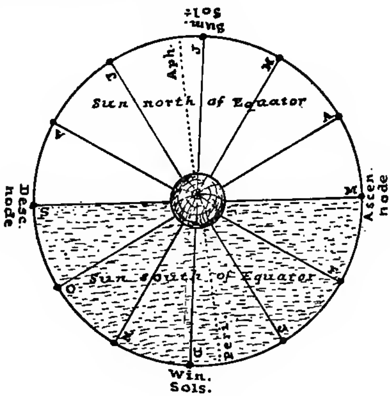


Fig. 38.

The full radial lines divide the circle into 12 parts corresponding to the 12 months of the year, but instead of marking the beginnings of the months they indicate from the 20th to the 23rd of the month, and the round dots indicate the positions of the sun at these dates. The months are denoted by their initial letters. Thus M at the ascending node means March 20th, S at the descending node, Sept. 23rd, etc.

The dotted line is the *line of apses* joining the perihelion and the aphelion.

As the sun moves most rapidly near perihelion and most slowly about aphelion, it is readily seen that the sun will move from the descending node around by the winter solstice

to the ascending node, in less time than it will do the remaining half of the orbit. Or, in other words, as the summer solstice is north of the equator, the sun should be north of the equator for a longer period than it is south of the equator. This will be practically shown by counting as follows:

Sun north of Equator		Sun south of Equator	
March	11 days.	September	7 days.
April	30 days.	October	31 days.
May	31 days.	November	30 days.
June	30 days.	December	31 days.
July	31 days.	January	31 days.
August	31 days.	February	28 days.
September	23 days.	March	20 days.
Total	187 days.	Total	178 days.

It thus appears that in the northern hemisphere the spring and summer together are about nine days longer than the autumn and winter together. In the southern hemisphere matters are, of course, reversed.

It might appear, at first, that the earth receives more heat from the sun while the sun is north of the equator than it does while the sun is south of the equator, since the former period is nine days longer than the latter. But as the sun is farther away during the former period than it is during the latter the difference in time is compensated by the difference of distance, and the amount of heat received during each period is the same.

35. The Zodiac.

Five planets, not counting the earth, which was supposed to be the centre, or the moon, were known to the ancients, namely, Mercury, Venus, Mars, Jupiter and Saturn. These, while appearing to travel around the earth, really travel around the sun, each in its own respective orbit, and the planes of these orbits extended to the heavens give us five great circles; and the plane of the moon's orbit gives us a sixth. These six circles, while each crossing the ecliptic at two opposite points called their respective nodes, yet lie so

near the ecliptic that none of them depart from it at any point by an angle as great as 9°, while for the most of them the angle of departure is far below this limit.

If, then, we consider a belt about the heavens, extending in breadth to 9° on each side of the ecliptic, or 18° in all, this belt forms a pathway, or highway, so to speak, along which the sun, the moon, and all the older planets appear to travel. This belt is called the *zodiac*.

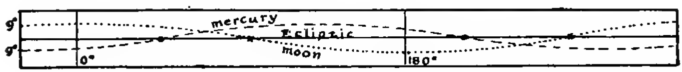


Fig. 39.

The figure represents the zodiac as if cut across and opened into a flat belt, which should be in the proportion of 20 in length to 1 in breadth, but of which the width is exaggerated in order to make it more distinct. The line through the middle is the ecliptic or apparent path of the sun. The dotted curved line represents the track of the moon, and the curved line of short strokes, the path of the planet Mercury, both for the year 1880. The points at which the paths cross the ecilptic are the nodes and are marked by round dots.

The origin of the zodiac is lost in the obscurity of the past. But it probably originated with the early Chaldeans or Babylonians, if not even earlier, as picture drawings of the zodiac are found in prehistoric and ancient remains in parts of the world far removed from one another, as in Babylonia, Egypt, India, Mexico, etc.

That the zodiac should be of singular importance in ancient times is quite natural. For the only bodies in the celestial vault that appear to possess the power of moving from place to place at will, and thus seem to be endowed with life, are the sun, the moon, and the visible planets. To the ancient priest-astronomer, then, these appeared to be gods or the dwellings of gods; and next to the gods themselves,

what could be of greater interest than the broad and well-travelled pathway which they followed in their march through the field of stars?

As to the division of the zodiac into parts or regions, it appears to have been at first divided into 6 parts, which were afterwards increased to 12; however, there is some uncertainty about this. In later times, however, the zodiac was divided into 12 parts, thus forming 12 constellations, or groups of stars, known as the 12 signs of the zodiac. These are mostly named after animals which they were supposed to represent, although the real significance of the names is probably to be traced much further back. The name *zodiac* is from the Greek word for an animal.

The zodiac has come down to us almost unchanged, and the names of the constellations and the symbols which stand for them are here given:

1. ♈ Aries, or the Ram.
2. ♉ Taurus, or the Bull.
3. ♊ Gemini, or the Twins.
4. ♋ Cancer, or the Crab.
5. ♌ Leo, or the Lion.
6. ♍ Virgo, or the Virgin.
7. ♎ Libra, or the Balance.
8. ♏ Scorpio, or the Scorpion.
9. ♐ Sagittarius, or the Archer.
10. ♑ Capricornus, or the Goat.
11. ♒ Aquarius, or the Waterbearer.
12. ♓ Pisces, or the Fishes.

The English names are also very neatly introduced in the accompanying rhyme:

The Ram, the Bull, the heavenly Twins,
And next the Crab, the Lion shines,
The Virgin, and the Scales,
The Scorpion, Archer, and he-Goat,
The man who bears the Watering-pot,
And Fish with glittering tails.

These constellations, like all others, are irregular in outline, of no definite form, they over-reach the limits of the zodiac belt, and fail to fill in to such an extent that other constellations, not of the zodiac, occasionally trespass on the belt in order to avoid open spaces in the heavens.

The scheme, as it stands, can scarcely be called scientific, and any scheme that could be adopted would labor under unavoidable difficulties.

The sun, as seen from the earth, appears to travel through these 12 constellations or signs of the zodiac in each year, thus entering a new constellation every month. Some 2000 years ago the beginning, or first point, of Aries marked the vernal equinox or ascending node; that is, the equator crossed the ecliptic at the line of division between Pisces and Aries.

But slow changes in the heavens, the nature of which will be more fully considered hereafter, cause the equinoxial points, and hence the beginnings of the seasons, to slide backwards, as it were, along the ecliptic; so that no relation in position between the equinoxes and the constellations of the zodiac can be a permanent one.

During the past 2000 years the equinoxes have shifted backwards nearly a whole sign, so that the vernal equinox is now at the beginning of the constellation Pisces. In 2000 years more it will be at the beginning of Aquarius; and something over 4000 years ago, when the ancient Babylonian empire was predominant, spring began when the sun entered Taurus.

As crude and unscientific as this scheme may seem to be, it is so woven into ancient history and chronology, and into the whole usage of astronomy, that it would not be profitable to change it. or to throw it aside, even if we could.

The best that we can do is to adopt, for certain purposes, a sort of conventional system which connects permanently the names and symbols of the zodiacal signs with the seasons of the year.

Thus it is a usual thing to say that the first meridian passes through the first point of Aries, or that spring begins when the sun enters Aries; and in the names tropic of Cancer and tropic of Capricorn we are using the words Cancer and Capricorn in this way. But we must bear in mind that Aries, Cancer, Capricorn, etc., when used in this conventional sense do not mean the same things as when applied to the constellations of stars.

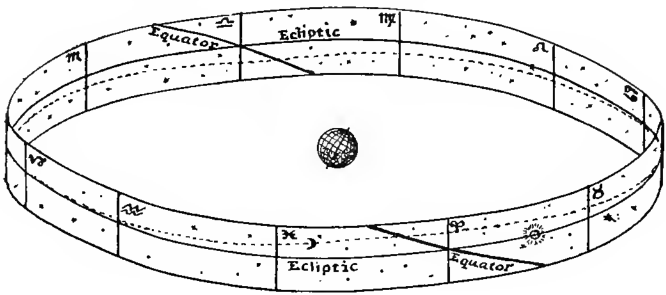


Fig. 40.

The diagram gives a perspective view of the zodiacal belt as seen from without, if such a thing were possible, showing the ecliptic, the equator crossing it at the nodes, and the path of the moon, the latter being variable. This is according to the conventional zodiac, for according to the constellational one the equator would cross the ecliptic at ♓ and ♍.

The zodiac, marking as it does the courses of the sun, moon, and planets throughout the year, and thus connecting itself in a prominent way with the holidays, the feasts, the variation of the seasons, and almost everything which comes into closest relation with human life, exercised a sort of mystic influence over all primitive people who had entered upon the early stages of civilization, and many of their ideas are still current amongst us in a more or less modified form, as for instance, the supposed influence of the moon or planets when in certain signs.

The accompanying figure represents a zodiac which is now in the museum of the Louvre in Paris, but which was found built into an ancient temple at Denderah in Egypt.

Besides the signs of the zodiac, which are easily traced by the animals representing them, the figure apparently pictures

Fig. 41.

all the constellations visible at that locality, mixed up with mythological and other symbols; for early astronomy and mythology were quite intimately connected.

A figure of a man surrounded by the signs of the zodiac is usually to be found upon the second or third page of every cheap almanac. This is a remnant of old astrology, and has reference to the influence which the moon was supposed to have over the different parts of the body, according as it was in one or other of the signs of the zodiac when the person was born.

36. The Seasons.

It is to the obliquity of the ecliptic that we are indebted for our orderly rotation of seasons.

If the ecliptic coincided with the equator, or, what is the same thing, if the earth's axis were perpendicular to the plane of the ecliptic, the sun would not swing from north to south and back again as it does now, but would be perpetually over the equator. And thus, holding daily throughout the year the same relation to any one given place, there could be no seasons, but spring, summer, autumn, and winter would be merged into one dead uniformity.

This does not necessarily mean that such a state of matters might not be very good indeed, nor does it mean that there would be no variations in the state of the weather from day to day. But it does mean that things would seem somewhat strange to us who are accustomed to revel in the ever-varying scenes of the changing seasons.

In the accompanying figure *E* is the earth, *S* the sun, and *Ec* the ecliptic.

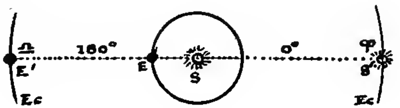


Fig. 42.

As seen from *S* the earth appears at *E'* in the ecliptic, and as seen from *E*, the sun appears at *S'* in the ecliptic. But *S'* and *E'* are opposite points, so that when the sun appears to be in Aries we would have to say that the earth is in Libra, as seen from the sun.

Now as we have to make our observations from this earth as our standpoint, this continual reverting from the place of the sun to that of the earth would be, not only troublesome and confusing, but a serious disadvantage.

And as motion is relative, and phenomena are unchanged, astronomers long ago decided to take things in this connection as they appear to be, to look upon the earth as being

fixed, and to record the positions and motions of the sun instead of those of the earth. Thus in any good ephemeris one finds recorded the right ascension, declination, and longitude of the sun, and not of the earth.

In this sense, then, the right ascension of the sun is zero when at the vernal equinox and 180° when at the autumnal equinox. And this is the usage that we shall here follow.

The earth's axis is inclined at the angle 66° 33′ to the plane of its orbit, and its direction in space is fixed, except as to a very slow change to be considered later on. As a consequence, whether we consider the earth as going around the sun or the sun as going around the earth, the radius vector will be, at certain times, perpendicular to the earth's axis, and at other certain times be inclined to the axis at the minimum angle of 66° 33′, while at intermediate times the angle will be intermediate.

Spring. The beginning of spring is when the sun arrives at the vernal equinox, about March 20th or 21st, depending on the occurrence of leap year.

The earth's radius vector is then perpendicular to the axis,

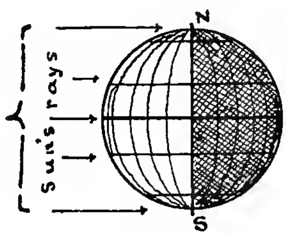


Fig. 43.

and the sun is accordingly vertical over the equator and it illuminates one-half of the earth's surface from pole to pole.

As the earth rotates daily upon its axis every place on its surface, except the poles, has 12 hours day and 12 hours night. Hence the term *equinox*, when the time from sunrise to sunset is equal to that from sunset to sunrise.

Both the northern and the southern hemispheres are now enjoying the same length of day, but the southern is coming out from its summer of long days, and passing on to its winter of short days, while the northern is leaving its winter of short days and moving onwards to its summer of long days. And thus spring in the northern hemisphere is contemporaneous with autumn in the southern.

Summer. Summer begins when the sun arrives at the summer solstice, about June 23rd. The radius vector is now inclined to the axis at the angle 66° 33′, and the north pole leans towards the sun.

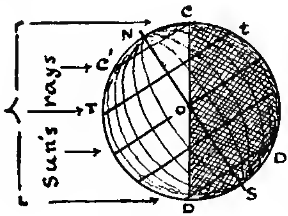


Fig. 44.

The sun is vertical over the point *T* which, by the rotation of the earth on its axis, determines the circle *Tt*, 23° 27′ from the equator. This is called the *tropic of Cancer,* the name being due to the circumstances that the sun, having arrived at its farthest position north, is turning (τρεπειν, to turn) to go back, and this takes place when the sun enters the conventional sign of Cancer, or the crab. It has been said, in fact, that the constellation was so named because the crab has a habit of walking backwards.

The rays of sunlight reach beyond the north pole to the point *C*, which determines the circle *CC′*, 23° 27′ from the pole, and which is called the *Arctic Circle.*

On the other hand, the rays of the sun fail to reach the south pole, coming only to *D*, which determines the *Antarctic Circle DD′* at the distance 23° 27′ from the south pole.

As the circle *COD*, which separates between day and night, bisects the equator, as at *O* and *O′*, upon the opposite side of

the earth, all places on the equator have equal day and night. But as one goes northwards from the equator the day gets longer and the night shorter until the Arctic Circle is reached. Beyond this the sun does not set, but moves in a circle around the horizon without passing below it, and thus it is all day and no night. And finally when the pole is reached the sun travels around in a circle parallel to the horizon and 23° 27′ above it.

As one goes south from the equator the day grows shorter and the night longer until the Antarctic Circle is reached, and beyond this it is perpetual night.

The north point of Norway is north of the Arctic Circle, so that anywhere near the 23rd of June one can, from North Cape, see the midnight sun for a number of days (for there are no nights) in succession. There is no inhabited country within the Antarctic Circle.

The foregoing is a description of the extreme case, when the sun is farthest north, or at the summer solstice. But the intelligent reader will understand how the description will have to be modified to suit the case where the sun is on its way northward, or on its way southward, after having passed the summer solstice. Also it will be easy to comprehend the state of affairs when the sun is at the autumnal equinox or at the winter solstice.

Autumn. This season begins when the sun reaches the autumnal equinox. The relative positions of the earth and sun are exactly as they were at the vernal equinox, that is, the sun shines from pole to pole and the days and nights are equal throughout the world. But there is the difference, which shows itself in the whole aspect of the vegetable kingdom, that the northern hemisphere is now passing from summer into winter, and the southern, from its winter into its summer.

Winter. Winter begins when the sun arrives at the winter solstice, about December 21st. The radius vector is again inclined to the earth's axis at an angle of 23° 27′, but the south pole is now turned towards the sun.

The sun is vertical over the circle $T't'$, called the *Tropic of Capricorn*, because the sun is turning to go north and is entering the conventional sign of Capricornus.

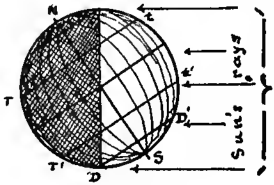


Fig. 45.

In the northern hemisphere the days are short and the nights are long, while the very opposite condition exists in the southern hemisphere. The Antarctic Circle is all light and the Arctic Circle is all dark.

A number of north pole seekers have spent long, dark winters in the Arctic Circle, and a good description of such an experience is to be found in "Kane's Arctic Explorations."

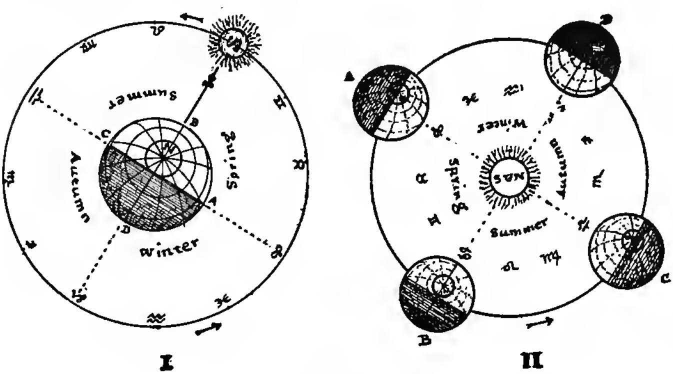


Fig. 46.

In figure 46 we have the seasons illustrated from both points of view. In I the earth is represented as being at the centre and the sun S travels around it. N is the north pole, and the illuminated hemisphere is always next the sun, and

covers one-half the circle *ABCD*. As the sun and illuminated hemisphere move around together it is easily seen how the north pole changes its relation to the light and dark parts, and in these changes brings in the seasons.

In II, the sun is at the centre and the earth travels around it. And as the earth's axis is fixed in direction the position of the pole is the same for all the positions *A, B, C,* and *D.* And it will be noticed that the illuminated hemisphere travels around the globe exactly as in I.

One sees from this diagram that, as far as explanation of phenomena is concerned, it is immaterial which view is taken.

37. Celestial Longitude and Latitude.

We have already considered two systems of indicating the position of a body in the celestial sphere. First, by giving its altitude and its azimuth. This is known as the horizontal system of coordinates, the horizon being the equator of the system and the zenith being the pole. Second, the equator system of coordinates, where the celestial equator is the equator of the system and the celestial north pole is the pole. The measures having reference to these are right ascension and declination.

We have now a third system known as the *ecliptic system* in which the ecliptic is the equator of the system and the pole of the ecliptic, a point in the constellation Draco, 23° 27′ from the celestial north pole in the direction of the winter solstice, is the pole.

The measures in this system are *Longitude,* which is measured in angle from the vernal equinox around the ecliptic in the direction in which the earth travels, and *Latitude* which is measured from the ecliptic towards the pole of the ecliptic. Thus celestial latitude and longitude are quite different from terrestrial measures of the same names.

The sun has longitude zero when it is at the vernal equinox, and in the Nautical Almanac its longitude is given for every day in the year.

As the sun apparently moves in the ecliptic, its latitude is zero constantly, except for a slight disturbance produced by

the planets, but as this disturbance never reaches more than a single second of angle, it need not be considered here.

The sun's longitude does not increase uniformly from day to day, because the sun's velocity is greater at perihelion than at aphelion. Thus a reference to the Nautical Almanac shows that the increase in the sun's longitude from Jan. 1st noon to Jan. 2nd noon, or in 24 hours, is 61'.9", while from July 1st noon to July 2nd noon it is only 57' 12"; and these quantities are proportional to the sun's apparent velocities at these times.

Referring again to the quantities recorded in the ephemeris, we find, at the times of the equinoxes and the solstices, the following peculiarities in the daily increase of the sun's right ascension as compared to its daily increase in longitude:

	Change in long. in 24 hrs.	Change in rt. ascen. in 24 hrs.
Sun at vernal equinox	59' 33"	53' 55"
" " summer solstice	57' 13"	62' 22"
" " autumnal equinox	58' 47"	53' 12"
" " winter solstice	61' 6"	66' 38"

We notice that the increase in longitude does not vary very much, and that it is greatest at the winter solstice, which is near the perihelion, and least at the summer solstice, which is near the aphelion, as we would expect it to be. But it is different with the right ascension, the increase being nearly the same at each equinox, but greater and considerably different at the solstices.

Also the increase in longitude is greater than in right ascension at the ~~solstices.~~ equinoxes

The irregularity in the increment of longitude is due to the elliptic form of the earth's orbit and the sun being at a focus, as has already been pointed out. But the irregularity in the increase of right ascension, while partly due to the same cause, is also partly due to another matter which we now propose to explain.

In the figure P is the north pole of the heavens, and P' is the pole of the ecliptic, $P'P$ being a part of the solstitial colure.

VE is the equator and VC is the ecliptic. Then V is the vernal equinox. Let the sun be at V, some time on March 20th, and 24 hours afterwards let is be at S.

Draw the meridian PSS', to meet the equator at S'.

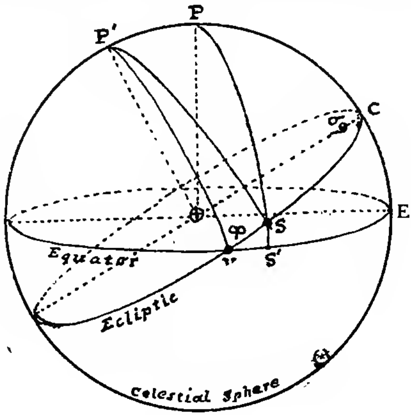


Fig. 47.

Then the arc VS represents the sun's increase in longitude for 24 hours at the vernal equinox, and VS' represents the sun's corresponding increase in right ascension.

But as SVS' is nearly a plane triangle, and $SS'V$ is a right angle, VS is greater than VS'. Or, *at the equinoxes longitude increases faster than right ascension.* But when the sun comes to C its longitude is 90°, and so is its right ascension. Hence *at and near the solstices the sun's right acsension increases faster than its longitude.* And the second cause for the irregularity of increase in the right ascension of the sun is the circumstance that longitude and right ascension do not belong to the same coordinate system; and it would be a problem in spherical trigonometry to change the one into the other.

However, we see that the motion of the sun is not uniform in either longitude or right ascension, and this has an important bearing upon our next subject.

TIME.

Time is measured naturally by the sequence of events connected with certain motions of the heavenly bodies.

The revolution of the earth on its axis is the best realization known of an ideal uniform motion; and the apparent rotation of the sphere of the heavens about the earth, which is an equivalent for the rotation of the earth about its axis, is necessarily of equal uniformity. Thus any fixed star, from its rising to its setting, measures out angle with absolute uniformity. And the local meridian of any given place on the earth travels along the celestial equator at a perfectly uniform rate. We must adopt some means, then, to make this uniform motion our measurer of time.

38. Siderial Time.

Let PhP be the local meridian of a place K upon the earth, E, where P, P' are the north and south poles of the celestial

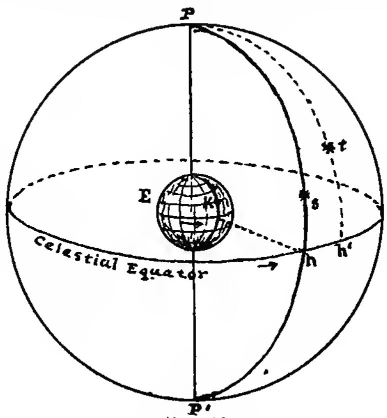


Fig. 48.

equator, and h the point where the local meridian crosses the equator. Then as the earth rotates on its axis, the point h sweeps along the equator with a uniform motion, measuring out equal angles in equal times.

Let the local meridian pass through the star S at any particular time. Then the period of time occupied by this meridian in passing from S around to S again is the time required for one rotation of the earth on its axis, and this is called a *siderial day*. The siderial day is divided into 24 siderial hours, and each of these into 60 siderial minutes, etc., thus giving that system known as siderial time.

If the celestial equator were a real line in the heavens and were graduated into 24 hours, and again into minutes and seconds, the line Oh would become the hour hand of a great siderial clock which would indicate time with the utmost precision. But instead of this we have only the stars as indicating figures upon our celestial dial and the plane of the local meridian as the hour hand of the clock. And the stars are not distributed at equal distances from one another or according to any known system, but are apparently scattered haphazard over the surface of the heavens, and yet the astronomer has finally to appeal to the stars for the determination of his time.

But for a number of reasons which cannot be given here, although some of them will appear in the sequel, the appeal to the stars is not always as simple an operation as it may be thought to be. Besides, the stars are not always visible. Hence the astronomer brings to his aid

39. The Siderial Clock.

The siderial clock, if correct, reads zero whenever the local meridian passes through the vernal equinox, or, in other words, the vernal equinox is on the local meridian. So also the siderial clock reads 6 hours when the summer solstice is on the local meridian, and 18 hours, when the winter solstice is on this meridian.

In short, the hour hand of the siderial clock, in its passage over the dial, represents the local meridian in its passage over the heavens. And if the clock be so placed as to have the arbor of its hand parallel to the earth's axis, and its face turned northwards, and the hour hand set to point to the first celestial meridian, it will always point to that meridian.

Let h be the vernal equinox. The local meridian is at h at

time 0. Let it require H hours for the local meridian to pass from h to h'. Then hh' measured in time is the right ascension of t, a star on Ph', and it is also H hours. Hence *the right ascension of a star is the siderial time at which the star comes to the meridian, or culminates.* Thus, if the right ascension of the star Regulus be $10^h\ 2^m\ 1^s$, this is the siderial time of the star's culmination; or the star will be 'on the meridian' at that time by the siderial clock.

A clock, however, cannot be made to go with the uniformity of the earth in its axial rotation, and has therefore to be corrected from time to time. Suppose that the altazimuth is set exactly in the meridian, and through it a star whose right ascension is given in the almanac as $3^h\ 8^m\ 43^s$ is seen to cross the central thread at $3^h\ 4^m\ 52^s$ by the siderial clock. Then as the clock should have shown $3^h\ 8^m\ 43^s$ when the star was on the meridian, the clock is $0^h\ 3^m\ 51^s$ slow.

The form of altazimuth used for this purpose has no vertical axis, but a horizontal one only. It is called an astronomical transit, and is one of the chief instruments of the astronomer.

The transit is adjusted with great care so as to have its line of sight trace out the meridian, and its field is usually crossed with equidistant vertical threads, and two horizontal ones near together. The purpose of having a number of vertical threads is to furnish the observer with the mean of a number of readings, as this will in all probability be more accurate than a single reading would be. Thus, suppose a star is seen to cross the five threads at the following times as shown by the clock: $A \ldots 8^h\ 3^m\ 27^s$, $B \ldots 8^h\ 5^m\ 14^s$, $C \ldots 8^h\ 7^m\ 2^s$, $D \ldots 8^h\ 8^m\ 50^s$, $E \ldots 8^h\ 19^m\ 36^s$. The mean of these is $8^h\ 7^m\ 1^s.8$, differing by $0^s.2$ from the reading of the middle thread.

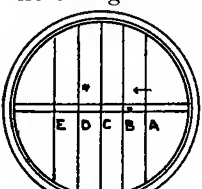


Fig. 49.

40. Mean Time.

If the star S had a slow but uniform movement in right ascension, say $1°$ per day, we could still count our time by

that star, if circumstances required it, the only difference being that the day would not mean the time taken by the earth to make an axial rotation, but a length of time depending upon this and the motion of the star. But all days would still be of uniform length.

The siderial day is an exact unit of time and is of great importance in astronomy, but it is not adapted to the common business of life. For this purpose we need a day having a relation to light and darkness, and hence to the sun's position with respect to our local meridian.

Now, we cannot put the sun in the place of S as a moving star, for, as we have seen, the sun is irregular in its motion in longitude and still more so in its motion in right ascension.

To get over these difficulties we adopt the following fictions:

(1). We suppose a sun, which we shall call the *dynamic* sun, to move uniformly in the ecliptic, so as to coincide with the true sun at perihelion and at aphelion only. We then calculate the errors in the position of the true sun as compared with this dynamic sun. These are the errors due to eccentricity of the earth's orbit, and these taken as a whole will be called the *eccentricity error*.

(2) We assume a sun, called the *mean* sun, which moves uniformly along the celestial equator, coinciding with the dynamic sun at the equinoxes and the solstices. We calculate the errors in the position of the dynamic sun as compared with the mean sun. These errors are due to the obliquity of the ecliptic, and taken as a whole will be called the *obliquity error*.

Then the algebraic sum of the eccentricity error and the obliquity error gives us the error of the true sun as compared with the mean sun, and as the mean sun increases its right ascension uniformly it can replace the moving star S.

We shall have much to do with the mean sun, and we speak of this fiction as if it were a reality.

When the mean sun is on the local meridian it is *mean noon*, and the interval between two consecutive mean noons is a *mean* day, and all mean days are exactly of the same length. The mean day is divided into 24 *mean hours*, each

into 60 minutes, etc., and time so reckoned is called *mean time*.

Clocks used for domestic purposes are mean time clocks, and are supposed to keep mean time.

41. Solar Time.

When the real sun is on the local meridian the time is solar noon, and the time elapsing between two consecutive solar noons is a *solar day*. As the sun is irregular in its motion of right ascension, solar days are not of equal length, and clocks and watches are not constructed or intended to keep solar time.

The difference between mean and solar time is called the *equation of time*. The equation of time is given in the ephemeris from day to day, and it expresses at any time the error in the position of the real sun as compared to the mean sun.

The mean sun, being a fiction, cannot be observed, so that what we obtain directly from observations on the real or true sun is solar time, and this is brought to mean time by adding or subtracting the equation of time as the occasion may require.

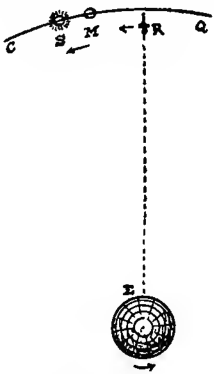


Fig. 50.

Let E, in the figure, be the polar projection of the earth showing the north pole, CQ be a part of the celestial equator,

S be the position of the real sun as referred to the equator, *M* be the mean sun on the equator, and *ER* be the local meridian of a given place.

The meridian, and *S*, and *M*, all move in the same direction, as indicated by the arrows.

In the case represented the true sun is ahead of the mean sun. But when the local meridian *R* reaches *M* it is mean noon, and it is not solar noon until the meridian comes to *S*, so that the true sun appears to be late in coming to the meridian, or slow. And so we have the seeming paradox:

When the sun's place, referred to the equator, is ahead of the mean sun, the *sun is slow*, and when behind the mean sun, the *sun is fast*. Or, the sun is slow or fast on mean time according as its right ascension is greater or less than that of the mean sun.

Graph of Eccentricity Error. As the true sun moves fastest at perihelion on January 1st, and slowest at aphelion on July 1st, it must be ahead of the mean sun and therefore slow from January 1st to July 1st, and behind the mean sun, and therefore fast during the remaining half of the year.

This error is represented in the accompanying diagram, which shows a graph of the eccentricity error for the year.

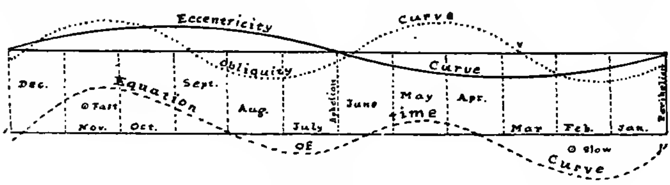


Fig. 51.

The straight line represents the time kept by the dynamic sun and extends from January to January again, the months being named. The curve line, by its departure from the straight one, shows the error of the true sun in relation to the dynamic sun throughout the course of the year. When the curve is below the line the sun is slow, and when above the line, the sun is fast.

Page 83. *Graph of Obliquity Error.* After the fourth line read: And as time and right ascension of the mean sun are both measured out uniformly on the equator, it is easy to see that, starting from the vernal equinox, the right ascension of the dynamic sun falls behind that of the mean sun, catching up to it again at the solstice; so that the dynamic sun is fast from the vernal equinox, Mar. 20th, to the summer solstice, June 23rd. Then slow from June 23rd to Sept. 23rd, then fast from Sept. 23rd to Dec. 21st, and slow again from Dec. 21st to March 20th.

The greatest departure, and therefore the greatest eccentricity error, is between 7 and 8 minutes.

Graph of Obliquity Error. We have seen that, starting from the vernal equinox, the sun's longitude increases faster than its right ascension, but that they are the same, each being 90°, when the summer solstice is reached. And as time and right ascension are both measured by motion in the equator, we see that the dynamic sun is ahead of the mean sun, and therefore slow, from the vernal equinox to the summer solstice, that is, from March 20th to June 23rd. Similarly, the dynamic sun is fast from June 23rd to September 23rd, slow from September 23rd to December 21st, and fast from December 21st to March 20th.

This is represented in the dotted graph.

Graph of Equation of Time. The error known as the equation of time is the sum of the two foregoing errors. So that to obtain the graph of the equation of time we must combine these two graphs, by taking the first graph and bending its straight line so as to make it coincide with the curved line in the second graph, or, what comes to the same thing, by taking the algebraic sum of the corresponding ordinates of the two graphs with which to form a new curve. The result is represented in the third graph.

Tables are sometimes given of the equation of time for every day in the year, but these tables are of little use where accuracy is required. For, on account of slow changes, the same table would not be correct for any two consecutive years. To be of use, except as an approximation, such a table would have to be reconstructed for each current year.

We notice from the third graph that the sun agrees with the mean time clock only four times in the year, namely, about April 15th, June 13th, September 1st, and December 24th, and that it is about 14½ minutes slow on February 11th, and about 16⅓ minutes fast on November 2nd.

Noon Mark. A mark drawn along the edge of the shadow cast by a vertical line or upright post upon a level floor when the sun is on the meridian, is called a *noon mark*. It indicates the return of solar noon from day to day throughout

the year, and the equation of time gives the correction by which we change solar noon into mean noon. So the countryman who boasted of his clock because it always coincided with the *noon mark* was not possessed of a very good clock. To regulate a clock or a watch by a noon mark the equation of time must be applied. Thus, when the shadow is at the noon mark on February 10th, the clock should indicate about 14½ minutes past 12.

Similar observations apply to the use of the sun-dial, which is of the nature of a peculiarly extended noon mark.

The following table gives the equation of time to the nearest tenth of a minute for every third day of the year 1910, and it will be sufficiently exact for correcting the time given by a noon-mark or a sun-dial for any year.

The letter *s* indicates that the sun is slow, or comes to the meridian after 12 o'clock noon, and the letter *f* that the sun is fast and comes to the meridian before 12 o'clock noon.

TABLE OF EQUATION OF TIME.

	Day of the Month.									
Month.	1	4	7	10	13	16	19	22	25	28
Jan.	3.4s	4.5s	6.2s	7.5s	8.6s	9.7s	10.7s	11.6s	12.4s	13.0s
Feb.	13.7s	14.0s	14.3s	14.4s	14.4s	14.3s	14.1s	13.7s	13.3s	12.8s
Mar.	12.6s	12.0s	11.3s	10.6s	9.8s	9.0s	8.1s	7.2s	6.3s	5.4s
Apr.	4.1s	3.2s	2.4s	1.5s	0.7s	0.0	0.7f	1.4f	2.0f	2.5f
May	2.9f	3.3f	3.5f	3.7f	3.8f	3.8f	3.7f	3.6f	3.3f	3.0f
June	2.5f	2.0f	1.5f	1.0f	0.3f	0.3s	0.9s	1.6s	2.2s	2.8s
July	3.4s	4.0s	4.5s	5.0s	5.4s	5.8s	6.0s	6.2s	6.3s	6.3s
Aug.	6.2s	6.0s	5.7s	5.3s	4.8s	4.3s	3.7s	3.0s	2.2s	1.3s
Sept.	0.2s	0.8f	1.8f	2.8f	3.9f	4.9f	6.0f	7.0f	8.1f	9.1f
Oct.	10.1f	11.0f	11.9f	12.8f	13.5f	14.2f	14.8f	15.3f	15.8f	16.1f
Nov.	16.3f	16.3f	16.2f	16.0f	15.7f	15.2f	14.7f	13.9f	13.1f	12.2f
Dec.	11.1f	9.9f	8.7f	7.4f	6.0f	4.6f	3.1f	1.6f	0.1f	1.4s

42. The Siderial Year.

The time occupied by the sun in making one complete apparent circuit of the heavens, from a star to the same star again, is called a siderial year, and in this relation it is immaterial whether we consider the mean sun or the true sun, as each completes its circuit in the same length of time.

If we could observe the sun when it passes over and hides a particular star on two consecutive occasions, we would have a direct way of arriving at the length of the siderial year. But as this method is not practicable we must resort to some method which is.

The difference between the siderial clock and the mean time clock, that is, between siderial time and mean time, increases uniformly throughout the year. At the completion of a year this difference amounts to exactly one day. So that if we can find the amount of this increase for a given length of time, we can easily calculate the length of time required for the increase to equal one day. For if we record, in mean time, the meridian passage of a star, at any date, the same star will cross the meridian again at the same mean time, exactly one siderial year after that date.

Suppose, then, a certain star is observed to cross the meridian on March 14th at $11^h\ 44^m\ 32^s.4$ p.m., and that 30 days afterwards, on April 13th, the same star is observed to cross the meridian at $9^h\ 46^m\ 35^s.4$ p.m., both records being made in mean time.

As the star crosses the meridian at the same siderial time on both occasions, we have:

Gain of siderial time on mean time, $1^h\ 57^m\ 57^s$,
Period of time elapsed, $29^d\ 22^h\ 2^m\ 3^s$.

And our problem is, how long a time must elapse to make the gain one whole day? By putting these time quantities into seconds, and denoting the length of the year by y we have:

$$y = 2584923/7077 = 365^d.257 \text{ nearly.}$$

By taking the mean of a great number of observations, at longer intervals apart, the result obtained is:

$$y = 365.25636 \text{ days} = 365^d\ 6^h\ 9^m\ 9^s.6.$$

This length of the siderial year is expressed in mean days. And as the stars gain one revolution on the sun, or in other words, siderial time gains one day on mean time in a year, the siderial year contains 366.25636 siderial days.

The accompanying diagram may serve to make matters somewhat plainer.

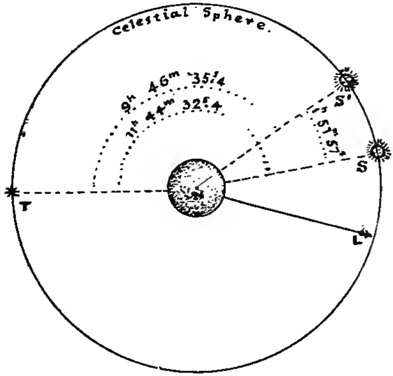


Fig. 52.

E is a polar view of the earth's northern hemisphere. *NL* is the local meridian, *S* and *S'* the positions of the sun in the ecliptic at the first and the second observations respectively, and *T* the position of the star.

As *L* sweeps around in the direction of the arrow, on March 14th it takes $11^h\ 44^m\ 32^s.4$ to go from *S* to *T*. But on April 13th the sun has moved forwards to *S'*, and it now requires $9^h\ 46^m\ 35^s.4$ for *L* to pass from *S'* to *T*.

The increase is the angle *SNS'*, and elapsed time is 30 days minus *SNS'*.

It is readily seen that in one complete revolution of *S*, *L* will pass *T* once oftener than it will pass *S*. So the number of siderial days in the year is one greater than the number of solar days.

To regulate a clock or watch by the stars. Siderial time gains one day on mean time in 365.256 days, nearly; so that

it gains 1/365.256, or 0.00273 days, nearly, in one day. This amounts practically to $3^m\ 56^s.5$.

But a star keeps siderial time; so that a given star will set $3^m\ 56^s.5$ earlier each evening when compared with the mean time clock.

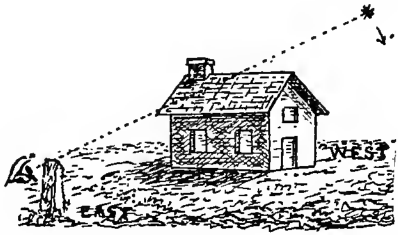


Fig. 53.

Place a post *P* at some distance east of a building *B*, and observe when some conspicuous star, not a planet, disappears below the roof or chimney of the building, keeping the eye in line with the top of the post and the top of the building, as represented. The time of the disappearance of the star will be $3^m\ 56^s$ earlier each evening. Thus if the watch shows $10^h\ 13^m\ 42^s$ when the star disappears on Monday evening, it should show $10^h\ 9^m\ 46^s$ on Tuesday evening, $10^h\ 5^m\ 50^s$ on Wednesday evening, etc.

Of course this does not give you any help in setting your time-piece to the true time, but only in correcting its rate of running.

43. Standard Time.

What is known as standard time is commercial in its idea and application rather than astronomical. In fact, it is somewhat of a nuisance to the practical astronomer, although of great benefit to the traveller. To illustrate it we will take a concrete example.

The longitude of Montreal is $4^h\ 54^m$ W., and of Toronto $5^h\ 17^m$ W., and the Grand Trunk Railway goes from the one

to the other. Suppose that the railway time-tables were made out for these two cities in terms of their respective mean astronomic times, and that a person at Montreal is supplied with a good watch correct to time. When this passenger arrives in Toronto his watch is 23^m fast, and unless he sets it to Toronto time, it is useless in directing him to the times of arrival and departure of trains at Toronto as given in the Toronto time-table. The case is similar when a person goes from Toronto to Montreal, except that his watch would be 23^m too slow on Montreal time, and confusion would be likely to follow.

The difficulty, as far as these two cities are concerned, might be got over by Toronto keeping Montreal time or reciprocally. But civic pride would come in here; besides it would not be the best solution of the difficulty.

The 5^h, or $75°$, meridian passes near Cornwall, between Montreal and Toronto, and by adopting the time of this meridian for both places Montreal time as so changed becomes 6^m slower than its mean astronomic time, while Toronto time becomes 17^m faster than its astronomic time, and neither of these changes or errors in time would be felt in commercial life, while the traveller would find his watch in agreement with the station clocks and the time-tables at both places. This is known as *standard time*; and the standard time for all Ontario and a good part of Quebec is the time of the 5^h meridian, or is exactly 5 hours behind Greenwich time.

Now this principle may be applied throughout the world theoretically as follows: All places between long. $0^h\ 30^m$ E., and long. $0^h\ 30^m$ W., to take Greenwich time; all places between $0^h\ 30^m$ E., and $1^h\ 30^m$ E., to take the time of the 1^h meridian; between $1^h\ 30^m$ E., and $2^h\ 30^m$ E., to take the time of the 2^h meridian, etc.; all places between $0^h\ 30^m$ W., and $1^h\ 30^m$ W., to take the time of the 23^h meridian; between $1^h\ 30^m$ W., and $2^h\ 30^m$ W., the time of the 22^h meridian, etc.

This, which is the principle of standard time, has been adopted by the majority of civilized nations, and where it

prevails all business and local time-pieces indicate the same minute and differ only by a whole number of hours.

In the practical application of the principle, departures from the theory have often to be made, the change of hour being more or less dependent upon circumstances. The change in the hour cannot well be made within the limits of a city or in the immediate vicinity of one, and is conveniently made at a boundary between nations or states, or along open stretches of country. Thus the standard time-piece goes back one hour in passing from Windsor to Detroit, or from Sarnia to Port Huron.

Five different times, as far as the hours are concerned, reach across the continent of North America, namely: Intercolonial time, Eastern time, Central time, Mountain time, and Pacific time. And Pacific time is exactly 4 hours behind Intercolonial time, and 8 hours behind Greenwich time.

It must be remembered that the heavenly bodies may not accommodate themselves to any such artificial arrangements, and that every observatory must have its mean time clock regulated to astronomical time.

Standard time at Kingston is $5^m\ 55^s$ ahead of local astronomic time.

PRECESSION OF THE EQUINOXES.

It has already been pointed out that while the ecliptic is the most immovable circle in the heavens, the conventional first point of Aries, or the ascending node, or the vernal equinox, is not a fixed point in the ecliptic. And as all the signs of the zodiac have a fixed relation to Aries, the conventional zodiac, so to speak, must shift along the ecliptic; or, the conventional zodiac slides around slowly over the constellational zodiac.

The cause of this motion will be referred to later on. At present we shall confine ourselves to a discussion of the nature and extent of the movement and the various phenomena dependent thereon.

S, in the figure, is the sun, moving from right to left along the ecliptic and approaching the ascending node A. AQ is the equator, and Am the meridian passing through the ascending node, that is, the first meridian.

This is in 1910, say, and the meridian passes through the star m. In 1920, 10 years after, A has moved to A', the

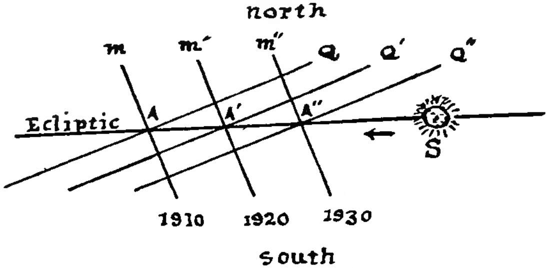


Fig. 54.

equator is now $A'Q'$ and the first meridian is $A'm'$ and passes through the star m'. In 1930, after another 10 years, A has come to A'', the equator is $A''Q''$ and the first meridian $A''m''$ passes through star m''; and so on from decade to decade, the movement of the node being in a direction opposite to that of the sun.

The *precession* of the node, which is in reality a retrogression, does not go on uniformly, being the outcome of the superposition of a number of slow cyclic changes which, in general, run their cycles in a few years. But upon the average the node travels backwards along the ecliptic at the rate of 50″.1 per year.

Now 50″.1 is contained in 360° about 25860 times. So that if this movement continues unchanged it will carry the node completely around the ecliptic in 25860 years. This is called the *annus magnus,* or great year.

This motion, as slow and inconspicuous as it is, has far reaching consequences which we shall proceed to study.

The siderial year is an exact and easily determined period of time, but it is not adapted to the common purposes of life. For it is evidently necessary that the year be so adjusted to

the seasons that the beginning of the year shall always be in the same season, and in the same part of that season.

But on account of the precession of the equinoxes it is impossible to make the round of the seasons coincide with the sun's motion amongst the stars for any great length of time. What we are compelled to do, then, is to institute a year of such a length that it will run concurrently with the seasons for all time to come.

But the seasons are connected with the arrival of the sun at the vernal equinox, and hence we must make the year to include the time taken by the sun to pass from the vernal equinox to the vernal equinox again. This is

44. The Tropical year, or Equinoctial year.

The node or equinox comes backwards $50''.1$ annually to meet the sun, and hence the tropical year must be shorter than the siderial year by the space of time required by the sun to pass over $50''.1$.

Now the sun describes $360°$ in the heavens in 365.25 days, nearly, and a little arithmetic shows that it passes over $\cancel{50''.1}$ in $20^m\ 19^s.9$, and this is the difference in length between the siderial year and the tropical year. Hence the

Tropical year$=365^d\ 5^h\ 48^m\ 49^s.7=365.242242$ days.

Leap year. The tropical year consists of 365.242242 days, which is not a whole number of days, and of which the fractional part is not an aliquot part of a day.

And yet, commercially and practically, we must make the year to consist of a whole number of days, which means that the practical year cannot be of invariable length.

Now 400 yrs. of 365.242242 days	=146096.897	days
and 400 yrs. of 365 days	=146000	"
Difference	96.897	"

So that 400 years of 365 days each would fall behind by 96.987 days. Adding one day to every fourth year, making it 366 days, will add on 100 days in the 400 years. This is 3.103 days in excess, so that we must take away 3 days in 400 years. The error will then be only 1 day in 4000 years,

a date too far ahead to concern ourselves about now. These corrections are provided for as follows:

1. Every year not evenly divisible by 4 consists of 365 days, and is a *common* year.

2. Every year evenly divisible by 4 consists of 366 days, and is a *leap* year.

Except, if it be a century year it is a leap year only when the number of the century is evenly divisible by 4.

Thus 1913 will be a common year; 1924 will be a leap year; 2000 will be a leap year, but 2100 will be a common year.

45. The Two Zodiacs.

We have two zodiacs, (1) the zodiac of the constellations, in which the names Aries, Taurus, etc., are connected with and denote fixed groups of stars, which groups are unchanged from generation to generation, and which were practically the same to the ancient Babylonian astronomer as they are to-day.

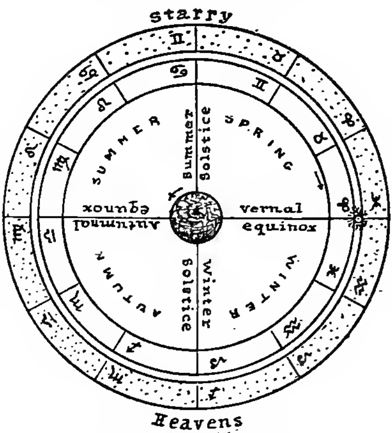


Fig. 55.

This is represented in the diagram by the outer ring, marked with star groups and the symbols of the constellations.

(2) *The conventional zodiac*, in which the symbols and names no longer apply to groups of stars, but to divisions of the tropical year, and are preserved on account of their convenience and their historical value. This zodiac is represented by the inner circle of the diagram.

The outer circle remains fixed, and the inner circle,—carrying with it the equinoxes, the solstices, the equator, the meridians, the poles, the circles of declination, and the conventional signs of the zodiac,—revolves within the outer circle from left to right at the slow rate of 50″.1 per year.

But even at this slow rate, the inner circle shifts, to the extent of one day's motion of the sun, in about 70 years, or to the extent of 30°, or one whole sign in 2150 years.

The limits of the constellations in star maps are not usually well defined, so that it is not easy to say where the constellations began and ended in early times. But this is certain, that if the vernal equinox coincided with the first point of Aries 2150 years ago, it must now coincide with the first point of Pisces. So that from this point of view the conventional sign of Aries agrees with the stellar sign of Pisces.

Some of the common almanacs ignore the conventional zodiac and tell you that the sun enters Pisces on March 20th, or at the beginning of spring. Such a view is highly objectionable. For if it be entertained, the sun will enter Pisces on March 21st in 70 years from now, and on April 1st in about 700 years from now. Or, in other words, if the equinox is at the first point of Pisces now, it will be at the 20th degree of Aquarius in 700 years from now. And thus the equinox will travel backward through the zodiac from year to year, and will have no fixed place among the signs. Only confusion can be the result.

The British Nautical Almanac adopts the more sensible view of keeping to the conventional signs of the zodiac and thus fixing the first point of Aries perpetually at the vernal equinox.

Some 4300 years ago, or about 2400 B.C., the old Babylonian empire was in the midst of its power, and it is probable

that the zodiac was brought into a definite form about that time.

But the vernal equinox was then at the beginning of Taurus. And we can well understand that the strength and subduing power of the sun-god at the beginning of spring—in overcoming the death-like gloom of winter, in freeing the brooks and ponds from their icy chains, in banishing to unknown parts the snow and sleet and chilling winds, in resurrecting again the tender plant and spreading out the verdant fields, and covering all by a radiant sky as an earnest of another season of warmth and comfort and plenty—was well typified by the Bull, the greatest and strongest of all domestic animals.

These ancient people represented the constellations through which the sun travelled during the gloomy and disagreeable parts of autumn and winter, when skies were lowering and surroundings dull and depressing, as species of monsters who held the sun in a sort of bondage and prevented it from sending down its rich gifts to man. Thus there was the scorpion-man, who guarded the gates of the underworld, the archer, who was half man and half some lower animal, the goat-man, as appears in the picture of the ancient zodiac, and the fish-man. And some writers hold that the Babylonian story of Marduke overcoming and subduing the monster Tiamut, a myth which in some form or other is of almost universal extent as symbolizing Creation, is only a mythological statement of the spring sun overcoming the rigorous terrors of winter.

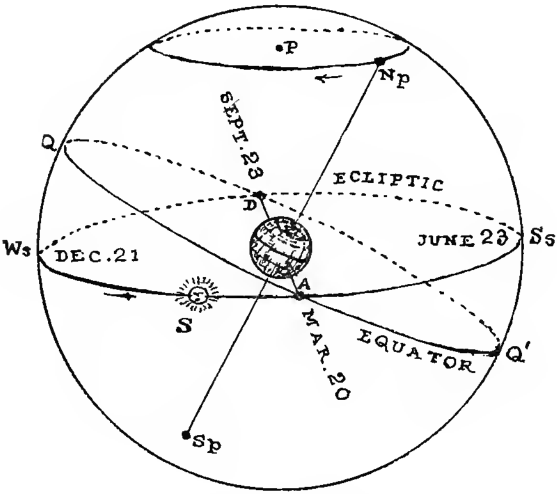
46. Movement of the pole and consequent changes.

The precession of the equinoxes or the backward motion of the node is due to the shifting of the earth's axis in space.

Let P be the pole of the ecliptic, and Np be the north celestial pole.

Let Np move in the circle NpR, having P' as its centre and an angular radius of 23° 27′, and let it complete its cycle in 25860 years. Then, as Np is the pole of the celestial

equator, this motion causes the equator to swing around so as to make *D* and *A* move backward along the ecliptic, while preserving unchanged the angle at which the ecliptic and the equator intersect.



The Pole Star. The star which is, at present, nearly at the celestial north pole is *Polaris* or *α Ursae Minoris,* and is in the tail of the Little Bear. It is about 1°.3 from the pole, but the motion of the earth's axis will carry the pole somewhat nearer to the star for a number of years to come. The pole, however, will pass the star at the distance of about a half degree, at its nearest approach, and will then move away upon its long journey of 25860 years before completing its circuit.

About 4000 years ago the nearest bright star to the north pole was in the constellation *Draco*; in a thousand years to come the pole star will be a small star in *Cepheus*; and in 13000 years the pole will be quite near to a conspicuous star in *Hercules.*

Change in declination and right ascension.

As the pole moves along its circular path its distance from a given fixed star is constantly changing, unless the star be at the pole of the ecliptic. That is to say, that the polar distance of the star, and hence its declination, is in a state of slow change owing to the precession of the equinoxes.

The change in declination is least, in fact zero, for stars situated on that meridian which is perpendicular to the path of the pole for the time being, that is, upon the solstitial colure. And from this it increases as the star is farther away until the maximum is reached for stars on the equinoxial colure.

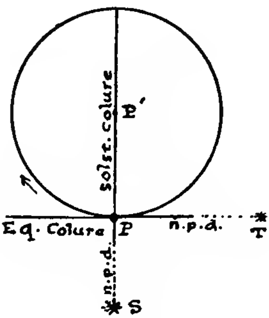


Fig. 56.

Thus if P be the pole, and P' be the pole of the ecliptic, PP' is a part of the solstitial colure, PT perpendicular to this is a part of the equinoxial colure. But SP, the north polar distance of S, is scarcely affected by a very small motion of P along the circle, while TP experiences the maximum effect.

In other words, this change in declination is least for stars whose right ascension is 6^h or 18^h, and greatest for those whose right ascension is 0^h or 12^h.

Also, owing to the motion of the vernal equinox the first meridian sweeps around the whole ecliptic in a retrograde

direction, so that the right ascensions of all the stars are upon the average slowly increasing.

As the ecliptic and its pole are the only elements that hold fixed relations to the stars, the *latitude* of a star is invariable, except for changes in the position of the star itself; but the *longitude* increases at the average rate of 50″.1 or $3^s.34$ each year.

Circle of perpetual apparition. The centre of this circle is the celestial pole, and its radius is the latitude of the place. As the pole changes place, so the circle of perpetual apparition must change its centre and the groups of stars which it includes.

Similar changes occur in the circle of perpetual occultation.

47. Causes of Precession.

We may say, in the beginning, that a perfectly spherical earth would have no precession. So that the remote cause of the precession is the earth's axial rotation, which causes the earth to become protuberant at the equator; and it is this protuberant mass which gives rise to the precession.

A rigid discussion of the reason for the precession cannot be given without the use of mathematics far beyond the scope of this work. But we can get a reasonable and instructive illustration of the matter which may, to some extent, take the place of demonstration, by experiments upon the behaviour of certain bodies in motion.

The really difficult part, however, of the problem is as to why the bodies in the experiment do as they do.

A is a top supposed to be rapidly spinning in the direction of the arrow, and to be in a position of equilibrium, with its axis vertical and at rest.

If a force, *F*, be brought to act for a little upon *P*, as by blowing a strong current of air against the axis, the pole will not respond in the direction of the force but will begin to move along a line *R* perpendicular to *F*. And *R* is the resultant direction of the rotation of *A* combined with the force *F*.

If the top have an iron spindle and be suspended from the pole of a magnet, as at B, and a force F be applied as before, we have the same phenomena as with A except that the resultant R is turned in the direction opposite to what it had at A. Moreover, if in A the spindle be inclined to the vertical, as at C, the pole P will undergo precession, travelling in a circle PQ about the vertical, in the direction in which the top turns. This is seen in a top that is wabbling.

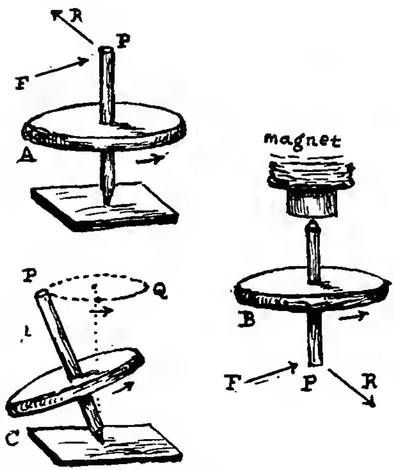


Fig. 57.

But, if the spindle be inclined to the vertical in B the precession will be in the direction opposite to that in which the top turns, that is, it will be retrograde.

It is not difficult to see why the cases A and B differ as they do. The position of equilibrium for the spinning top is that in which the axis is vertical.

But in the case of A this equilibrium is unstable, and if it be disturbed by pushing the axis out of the vertical the force of gravity tends to increase the disturbance and bring the pole farther out of the centre.

In *B*, on the other hand, the equilibrium is stable, and the force of gravity tends to correct any disturbance of equilibrium that may take place.

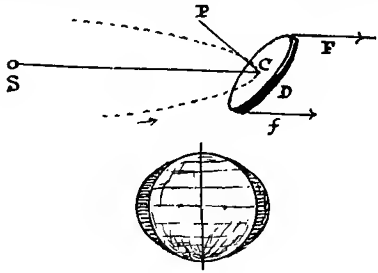


Fig. 58.

Now, in figure 58, let *SC* be a string attached to the centre, *C*, of a heavy circular disc *D*. Let *PC* be the axis of the disc, and let the angle *PCS* be less than a right angle.

If *C* is made to revolve rapidly about *S* as a centre, in a horizontal orbit, the centrifugal force will keep the string stretched, and the centrifugal force at *F* will be greater than that at *f*, as *F* moves in the larger circle; and the tendency will be to bring the plane of the disc to coincide with the plane of the orbit, or to bring *PC* to be perpendicular to *SC*.

Before this is effected, suppose that the disc is set in rapid rotation about its axis. Then, as we have seen in the case of the top *B*, the axis will undergo precession in a direction opposite to that of the orbital motion.

Finally, in the application, let *S* be the sun, and the disc *D* represent the protuberant mass along and around the earth's equatorial parts. The sun's attraction takes the place of the string and matters go on much as in our assumed experiment.

The pull of the sun tends to bring the plane of the equator into coincidence with the plane of the ecliptic, which would be a position of stable equilibrium, and the axial rotation of the earth so modifies the effect as to produce a retrograde precession of the axis and hence of the nodes.

We thus see that the effect of the sun in producing precession is zero when the sun is at the nodes and a maximum when the sun is at the solstices.

48. The Anomalistic year.

The time required by the earth to pass from the perihelion around to the perihelion again is called the *anomalistic year.* The sun's distance from the perihelion point is called the sun's anomaly, and is measured from 0° to 360°, and hence the name given to the year.

Now, the perihelion point in the earth's orbit is not fixed but moves in the same direction as the sun at the rate of 11″.25 per year. And as the sun requires $4^m\ 33^s.7$ to move 11″.25, the anomalistic year is $4^m\ 33^s.7$ longer than the siderial year. We have accordingly:

	Tropical yr.	Siderial yr.	Anomalistic yr.
Motion of ⊙ ..	359°.9861	360°.0000	360°.0031
Length in days.	$365^d.2422$	$365^d.2567$	$365^d.2595$

As 11″.25 is contained in 360° 115000 times, it requires 115000 years for the perihelion point to make one complete revolution. But as the equinox moves backwards one revotion in 25860 years. we get from the formula $ab/(a+b)$, which is adapted to this problem, where $a=115000$ and $b=25860$, the quantity 21000 years; and this is the time that it requires the perihelion to move from the ascending node to the ascending node again.

49. Eccentricity of Earth's Orbit and variations in climate.

The eccentricity of the earth's orbit is at present about 0.01677 or $^1/_{60}$. This quantity has a very long period of variation. It is at present growing less and the orbit is becoming more nearly a circle. The eccentricity will never reach zero, however, and the orbit will never be a circle. After passing the minimum the eccentricity will continue to increase for something like a hundred thousand years until it reaches a maximum, after which it will again decrease.

Variations in climate. At present the earth's perihelion passage is in winter in the northern hemisphere, and this has

some effect in modifying the cold of winter and the heat of summer and thus bringing in a somewhat more equable climate than would otherwise be the case.

In the southern hemisphere matters are reversed, and the tendency is towards a short hot summer and a long cold winter. And this seems to be borne out by the facts that the south pole is surrounded by ice to a greater extent than the north pole, and for a given high latitude the mean temperature is lower for the southern hemisphere than for the northern.

In ten or eleven thousand years matters will be quite changed around, the perihelion passage will be in July, the southern hemisphere will be enjoying a moderate climate, and the northern one will be subject to extremes.

If the earth's orbit were a circle, differences between the mean temperatures would not be so marked as at present, although the different distribution of land and water in the two hemispheres would undoubtedly have some effect. But if the eccentricity were much increased and the perihelion were at a solstice, the difference would be increased.

And it is easy to understand that with a high eccentricity we might have a winter so long that the following summer, although hot, would be too short to clear away the accumulation of snow and ice of the preceding winter. And this accumulation going on from year to year would bring in a veritable *ice age* in the polar regions of that hemisphere which had the perihelion passage in its summer.

As long as this high eccentricity existed there would be a succession of ice ages, shifting from one pole to the other, through intervening periods of moderation, as the perihelion passed through an equinox.

These periods of cold and ice would each last for some thousands of years, and would recur at either pole after lapses of about 21000 years.

Mr. James Croll has adopted this explanation of the occurrence of past ice ages in his "Climate and Time," and whether it is generally accepted by geologists or not, it seems very reasonable as, at least, a partial explanation.

THE MOON.

The moon, being the most conspicuous celestial object next to the sun, and undergoing such wonderful changes every month, has always been an object of particular interest to mankind. And we have not, as yet, fully dropped our faith in the moon's power over many things pertaining to man and his interests.

The word 'month' is connected with 'moon,' and certainly no more convenient measure of time, for periods longer than a day, is to be found in the motions of the heavenly bodies, than is presented in the consecutive changes of the moon.

Many people, such as the Indians of North America, counted their time and registered their events by moons, and many African tribes do so still. And in Captain Speke's travels in Africa he gives an interesting description of the feast of the new moon as kept by certain of the African chiefs.

50. The Moon's Motion.

A very little observation will show that the moon moves from west to east amongst the stars. For it is only necessary to compare the position of the moon with that of some bright star, near which it passes in its course, for a few evenings, or even for a few hours upon the same evening.

By measuring the angular distance of the star from the limb of the moon at about the same hour on consecutive evenings, we can readily make out that the moon moves forward in its orbit at a rate of a little over 13° in 24 hours, or a little above one-half a degree in an hour. And as the moon's angular diameter is about 31′, the moon apparently moves over a distance equal to its own diameter every hour. This apparent motion of the moon amongst the stars is far from being uniform. For the moon is sufficiently close to the earth to have its apparent position materially affected by parallax arising from the earth's axial rotation. Thus, while the moon is moving forwards in its orbit, the observer is also being carried forwards, and the effect is to displace the moon

in a retrograde direction. And thus the moon appears to move faster when rising or setting than when high in the heavens.

Besides there are real irregularities in the moon's orbital motion arising from the eccentricity of its orbit and from other causes.

The moon passes over and hides, or *occults*, as it is said, every star in its course, and the disappearance of the star behind the moon's disc is so sudden as to form a very distinct point of time.

By noting the elapsed time between two similar occultations of the same star after some hundreds of revolutions of the moon about the earth, it is not difficult to arrive at a close approximation to the moon's siderial period.

But as the moon's orbit is not fixed, but undergoes constant changes of one kind and another, the problem is somewhat more difficult than it might at first appear to be.

From a very large number of observations, and numerous corrections, extending over some hundreds of years, the moon's siderial period is accepted as being

$$27.32166 \text{ days, or } 27^d\ 7^h\ 43^m\ 11^s.4.$$

Taking the mean radius of the moon's orbit as 238000 miles, we readily find that the moon moves in its orbit at the average speed of

2280 miles an hour, or 38 miles a minute.

51. Moon's Synodic Period.

Let the earth E, the moon M, the sun S, and a star T be in

Fig. 59.

line. While the moon moves from T around to T again the sun has gone forwards from S to S' And our problem is to

find how long it will take the moon to go from S, not to S', but to the position where S will be when the moon overtakes it.

We solve this by the formula $t = ab/(a-b)$, for two bodies revolving about the same centre, when a is the time of revolution of the slower moving body, and b is the time of revolution of the other.

In the present $a = 365.25674$, the number of days in the siderial year, and $b = 27.32166$, the moon's siderial period. And the result of substitution is:

$$t = 29.53059 \text{ days}, = 29^d\ 12^h\ 44^m\ 3^s, \text{ nearly.}$$

This quantity of time is the *moon's synodic period*, or one *lunation*; and it is the interval of time between two consecutive new moons, or two consecutive full moons, etc.

52. Lunations in a year—Epact.

There are 365.2422 days in a tropical year and 29.5306 days in a lunation. And 365.2422/29.5306 gives 12 lunations with 10.875 days remaining. So that there are 12 new moons in a year, as also 12 full moons, etc.

The excess of 10.875 days lacks ⅛ of a day of 11 days. If we consider 11 days as the excess we will be one day out in 8 years. But if at the same time we take 30 days instead of 29.53 days for a lunation, the error will be only about 4 days in a century.

Now the *Epact* is the moon's age—that is, the number of days since the last new moon—on the first day of January. And we see that this number increases by 11 days annually. And when the increase makes it to be over 30, 30 is rejected and the remainder forms the epact. Thus the epact for 1910 is 19; for 1911 it will be found by adding 11 to 19, giving 30; for 1912 it becomes 11, etc.

These results, although only approximate, are sometimes convenient, as they serve to fix the dates of the new moons throughout the year, and they are seldom more than a day astray. The epact, which is given in the almanac for every

53. Moon's Phases.

year, is calculated through the *Golden Number*, which will be considered later on.

The most distinctive and interesting phenomena connected with the moon are the incessant changes in its visible form. These are due to the moon's being a dark body, shining only by the reflected light of the sun, and to the varying relative positions of the sun, the moon, and the earth, during a lunation.

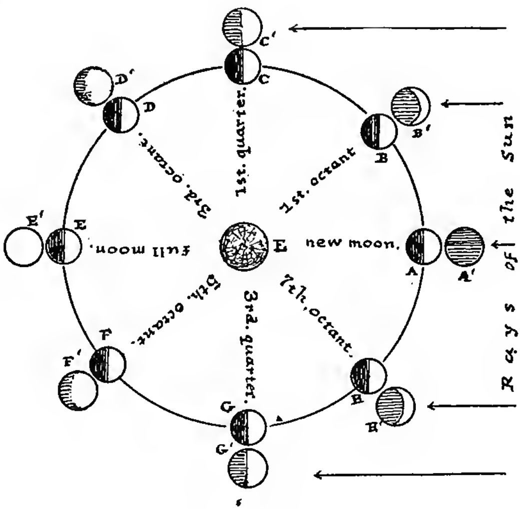


Fig. 60.

As the sun's distance from the earth is 400 times that of the moon, and the sun's diameter is nearly twice the diameter of the moon's orbit, the rays of the sun, as they come to the moon, may be considered as being parallel, in whatever part of its orbit the moon may be.

The diagram represents the earth E at the centre, the moon in 8 equidistant positions in its orbit, showing in each case the lighted half turned towards the sun, and in the positions

A', *B'*, *C'*, *D'*, *E'*, etc., the lighted portion of the moon as seen from the earth.

At *A* the sun and the moon have the same right ascension, and the moon is invisible, as at *A'*, because its dark side is wholly turned towards us, and also it is lost in the glare of the sun. This, as an astronomical event, is *new moon*; but popularly the term is applied to the moon when it is a couple or three days old, or when first seen in the west as a slender crescent.

At *B* the moon has completed one-eighth of its revolution and is in the *First Octant*. The figure *B'* shows that as seen from the earth the lighted part appears as a crescent facing westward, and covering about one-fourth of the moon's whole disc.

Moving on in its orbit the crescent grows wider until *C* is reached, when the moon has passed over one-fourth of its orbit, and the lighted portion has become a semi-circle. The moon is now in the *First Quarter*. Leaving this position, the face of the moon becomes *gibbous*, that is, one edge of the lighted portion is circular and the other edge elliptical. This is well seen at *D* and *D'*.

The elliptical edge is known as the *terminator*, and it undergoes a continuous change of form as the moon pursues its course.

At *E* the right ascension of the moon is 180° in advance of that of the sun, and it presents to us a full circle of light, and we have *Full Moon*. From this around to new moon again these phenomena and changes occur in a reversed order, and the lighted portion of the moon now faces eastward.

It is seen, then, that we have New Moon, First Quarter, Full Moon, and Last Quarter, according as the right ascension of the moon is 0°, 90°, 180°, and 270° in advance of that of the sun.

Also a very little consideration will show that from new to full the moon rises some time during the day and sets some time during the night, while from full to new it rises during the night and sets during the day.

54. Moon-light and Earth-light.

The earth and the moon are both dark bodies, and the earth, as well as the moon, shines by reflecting the sun's rays. Moon-light whenever present is always a pleasure in the relief that it gives from dark and gloomy nights, and the apparent gliding of the moon through broken clouds upon a summer evening is a thing of poetic beauty. And yet, according to Zöllner, the brightness of the full moon is only about one-six hundred thousandths (1/600000) of that of the sun.

The reflecting surface of the moon is of solid material, but of the earth it is nearly three-fourths water, and we cannot be certain as to how the ocean reflects the light of the sun. But as the moon's angular diameter is only 31′, while that of the earth as seen from the moon is 114′, the area of the earth's disc as seen from the moon is about 12 times that of the moon as seen from the earth. So that if the earth's *albedo*, or power of reflecting light, be one-half that of the moon's, the earth must give six times as much light to the moon as the moon does to the earth. We would expect, then, that when the moon's dark face is largely

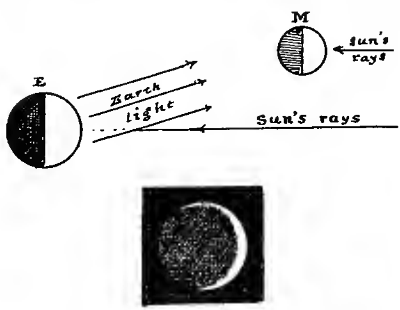


Fig. 60a.

turned towards us and is lighted by the full disc of the earth, the moon should be visible in earth-light. These conditions are fulfilled soon after new moon when we have the moon

as a slender crescent in the west after sunset, and again when it appears as a similar crescent in the east a little before sunrise.

In both cases the whole surface of the moon is visible with a faint ashy light bordered towards the sun by a narrow and brilliant crescent. This phenomenon, especially the evening one, is known as *the old moon in the new moon's arms.*

55. The Moon's Orbit.

As has already been said, the moon's orbit is an ellipse with the earth at one of the foci, and it accordingly has an apsis line, perigee, apogee and nodes.

The orbit is inclined to the ecliptic at an angle of 5° 6′, so that it has two nodes where it crosses the ecliptic, one being the ascending node and the other the descending node. These nodes, as is the case with the equinoxes, have a retrograde motion which carries them through a complete circuit of the ecliptic in about 18.6 years.

As the ecliptic is inclined to the equator at the angle 23° 27′, the inclination of the moon's orbit to the equator varies between the limits 18° 21′ and 28° 33′, running its whole course in 18.6 years.

We are now in a position to explain some interesting things in regard to the moon's presentation.

56. Wet, and Dry, Moon.

It will probably be a long time before the credulity of man will allow him to give up altogether his faith in the moon's influence over the weather. And the belief in a wet moon and a dry moon is a part of that faith. The serious difficulty is that followers of the cult are not always agreed among themselves; some holding that when the new moon lies well upon its back it is a dry moon, and some holding the very reverse. For our purpose we shall call the first of these cases a dry moon. And a wet moon will be when the crescent stands well up upon one of its horns.

In the figure, (I), the line *NS* represents the western horizon just after sunset, when the sun is near to and approaching the vernal equinox, which is on the horizon and just setting.

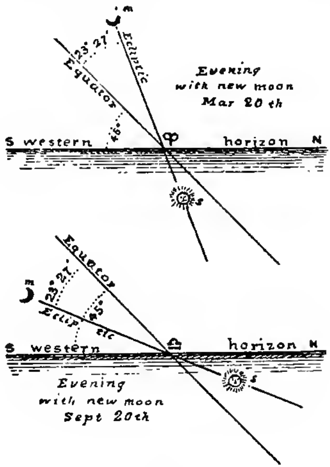


Fig. 61.

The latitude is supposed to be 45°N, so that the equator rises at an angle of 45° from the south; and the ecliptic rises at the angle 68° 27′ from the south. The sun is below the horizon, at *S*, and the new moon is near the ecliptic, at *m*. And it is easily seen that the crescent moon lies well upon its back, and being capable of holding water, is a *dry* moon.

In (II) we have the western horizon and the equator the same as in (I), but it is September, with the sun approaching the autumnal equinox, which is on the horizon and just setting.

The ecliptic is now inclined to the horizon at the angle 21° 33′ from the south. The sun has set, as at *S*, and the new moon, at *m* near the ecliptic, is standing upon its horn so as not to be able to hold water. This then is a *wet* moon.

These are the extreme cases. But they occur in a less marked degree when the sun is anywhere near one of the

nodes of the earth's orbit. In fact, starting from the vernal equinox, when the new moon is well on its back, the crescent becomes more and more tilted up until the case of the second figure is reached at the autumnal equinox; after which the tilting becomes less and less as the sun gets around towards the vernal equinox again.

But the important point is that we always have a dry new moon in March and a wet one in September. And the regularity in the sequence of variations should, to any intelligent person, be sufficient to throw discredit upon the whole theory of wet and dry moons.

57. The Harvest Moon.

The average time elapsing between the risings of the moon upon two consecutive nights is about 48 minutes. But for the full moon in September, and especially when it happens near the time of the autumnal equinox, the interval between consecutive risings may be as low as 27 minutes or even 21 minutes; so that to superficial observers the moon appears to rise almost at the same hour for several nights in succession. Long years ago, before the true explanation of this peculiarity was known, it was attributed to a special dispensation of Providence intended to assist the agriculturist in saving his harvest; hence the name of *harvest moon*. The full moon of October exhibits the same peculiarities but less extensively, and is sometimes called the *hunter's moon*, because it occurs in what is known as the hunting season.

We give here the explanation of the harvest moon for latitude 45°N.

In the autumn, when the sun is near Libra, the full moon, being opposite the sun, is near Aries.

The diagram illustrates the eastern horizon with the full moon on the horizon on September 23rd or thereabouts. The vernal equinox, ♈, is rising, and the equator, the ecliptic, and the two positions of the moon's orbit, when inclined in opposite sides of the ecliptic, are shown as they would be projected on the eastern sky under certain circumstances.

Suppose that on September 23rd, say, the full moon is rising as at *b*, and that it is moving in the ecliptic. Then on the 24th at the same hour the moon will be at *c*, and will rise when the horizon sinks through the distance *hc* by the earth's diurnal rotation.

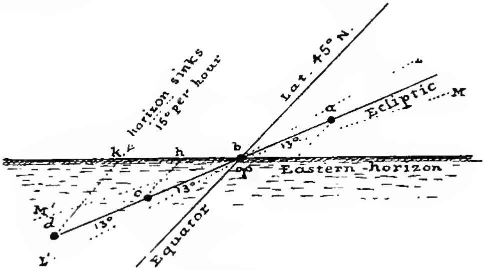


Fig. 62.

Now in the triangle *hbc*, *bhc* is 135°, *hbc* is 45°—23°27′, or 21° 33′, and the angular distance *bc* traversed by the moon in 24 hrs. is about 13°. Hence we readily find that the distance *ch* is about 6° 45′, equivalent to 27^m in time.

And thus the rising of the full moon at *c* on the 24th would be only 27 minutes later than the time of its rising at *b* on the 23rd. Similar explanations will apply to its rising when at *a*, and at *d*.

If the moon's orbit is situated as *MM′*, where *M′bd* is 5° 6′, the conditions are most favorable, and the difference between consecutive risings becomes only 21 minutes. And with the orbit situated as *LL′* the conditions are least favorable, the difference in consecutive risings working out to about 33 minutes. And we have an alternation of most favorable harvest moons with least favorable every 18.6 years.

And thus the harvest moon, while always favorable to agricultural interests, is a most natural outcome of the conditions prevailing, and varies from most favorable to least favorable and back again in 18.6 years.

For a latitude higher than 45° the harvest moon is still more favorable, and less so for a lower latitude.

58. Moon's Apsis line.

The line joining the apogee and perigee of the lunar orbit has a slow motion forwards, completing a revolution in about 9 years.

The relative distances of the moon at apogee and at perigee are as 9 : 8, the distances themselves being about 252000 miles and 224000 miles. This means a variation in angular diameter from 33′ to 29′ 30″. Now, the sun's angular diameter varies from 32′ 36″ to 31′ 32″. So that, although upon the average the moon appears to be somewhat smaller than the sun, the moon, when near perigee, appears to be larger than the sun, and if interposed between us and the sun would completely hide the latter.

59. Moon's Libration.

As everybody knows, the moon practically presents the same face to the earth, the reason of which has been already explained under the heading of 'The Tides.' On this account it is sometimes said that the moon does not rotate upon an axis. This is true in relation to the earth, but in relation to space, or absolutely, the moon rotates once on its axis in the same time as it makes its revolution about the earth.

In viewing a ball whose diameter is much greater than the distance between the eyes, we see somewhat less than half the surface of the ball. But if the ball were turned slightly on one side and then on another, we might be able to see somewhat more than half the surface, considering all the positions.

That shifting which enables us to see more than one-half of the moon's surface is called the *moon's libration.*

There are three causes for the libration, namely: 1. The eccentricity of the moon's orbit; 2. The inclination of the moon's axis to the plane of its orbit; and 3. The axial rotation of the earth.

1. A rotating planet cannot undergo a sudden change in its velocity of rotation, or in the direction of its axis. So

that although the moon rotates slowly, only once in 27 days, yet its rate is uniform. But, from Kepler's law II, this is not the case with the moon's motion in its orbit.

The diagram shows the moon's orbit with the earth at a focus, exaggerated in eccentricity in order to accentuate the illustration.

The moon is shown at perigee, at apogee, and half-way between these in time. Then, as the moon rotates uniformly,

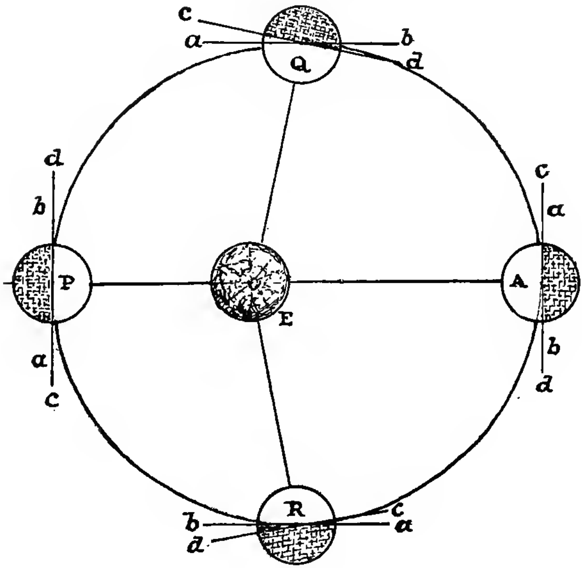


Fig. 63.

the tangent line *ab*, at *P*, will be as shown in the four positions. But *PQ* is greater than *QA*, and *PR* greater than *RA*. So that at *Q* we see beyond *ab* to *cd* on the *a* side, and at *R* we see beyond *ab* to *cd* on the *b* side.

This is called the *moon's libration in longitude*, and its amount is about 7° 30′ on each side of a central position.

2. The moon's axis is inclined about 6° 30′ from a normal to the plane of its orbit, so that when the north pole of this axis leans towards the earth we can see 6½ degrees beyond the north pole; and 14 days later the south pole leans towards the earth and we see 6½ degrees beyond the south pole.

This is the *moon's libration in latitude.*

3. If we change our position on the earth, not only is the moon affected by parallax, but we can see a little distance around the limb of the moon. If the moon passes through our zenith, we are carried, by the earth's rotation, between moon-rise and moon-set, through an angle, as seen from the moon, equal to twice the moon's horizontal parallax, or about 1° 54′, and we are enabled to see this far around the edge.

This is the *moon's diurnal libration*, and its amount depends upon the position of the observer upon the earth.

The result of all this is that, although we do not see quite one-half of the moon's surface at any one time, we see something more than one-half taken all together.

Stereograph of the Moon. By taking two photographs of the moon when in the same phase but, as near as is practicable, at extremes of libration, and uniting these in a stereoscope, we obtain a realistic view of the moon as a solid globe some 2 or 3 feet in diameter and 12 or 15 feet distant. The view is something such as would be obtained by a giant whose head was in the position of the earth and whose eyes were some thousands of miles apart.

The author has such a stereograph from negatives by L. M. Rutherford, and in it the moon appears to be somewhat of a prolate-spheroid form with the longer axis directed towards the earth; and this is probably the form which it would assume by virtue of the earth's attraction.

60. Nutation.

The moon attracts, not only the waters of the ocean to form the tides, but also the protuberant mass about the equator to produce a sort of precession of the equinoxes in much

the same way as the sun does, except that on account of the smallness of the moon, and the rapid change in its orbit, the effects are very small. This effect is known as the *lunar nutation.*

The effect is much the same as if the pole of the heavens travelled about a small ellipse, once in 18.6 years, while the centre of the ellipse moved in a complanar circle 23° 27′ from the pole of the ecliptic, making its circuit in 25860 years. The path of the pole is thus a sinuous motion imposed upon a circular one, there being about 1400 sinuosities in the circuit.

The dimensions of the ellipse are 7″ by 9″, so that the sinuosities are too small to be detected except by careful measurement.

ECLIPSES.

An Eclipse in astronomy is the passing of one heavenly body through the shadow of another.

We are concerned just now with what are called eclipses of the sun and of the moon. The bodies to be considered, then, are the sun which supplies the light, and the earth and moon which cast shadows.

The Shadow. *S* represents the sun and *E* the earth, or moon. The shadow cast by *E* consists of two cones. The

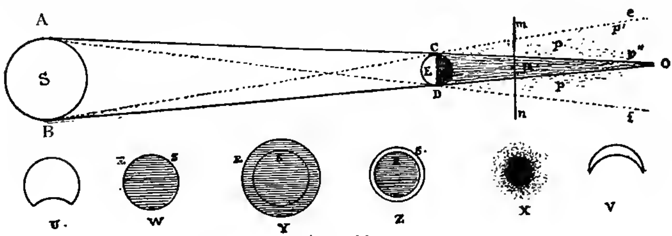


Fig. 64.

one *COD* from which all light is excluded is the *umbra* of the shadow, and the inverted cone, bounded in section by *Ce*

and Df, from which only a part of the light is excluded, is the *penumbra*.

A normal section of the shadow made by the plane mn is shown at X. The umbra gives the central dark portion, and the penumbra surrounds it, beginning with the darkness of the umbra and growing lighter as we pass outwards until the distinction between the penumbra and the full light is lost.

At O, the angles subtended by AB and CD are equal, and E just covers S and no more, as at W. At u, a point between O and E, CD subtends a greater angle than AB, and E appears large enough to cover S and to lap over to some extent, the extent being greater as u is nearer to E, as represented by Y. From any point to the right of O, E appears too small to cover S, and when superposed leaves a ring of S visible about E, as at Z.

At a point p', near the border of the penumbra, the body E appears to cut a small segment out of S, as at U; and at p'', near the border of the umbra, E appears to cover all but a small crescent of S, as at V.

If we suspend a ball in the rays of the sun, and cut the shadow by a piece of white cardboard held normal to the axis of the shadow, by moving the cardboard back and forth, we can study the character of the shadow with ease and satisfaction.

The earth and the moon, being dark bodies, cast their long black shadows far into space in a direction opposite to that of the sun, so that when the sun is in Aries the earth's shadow is in Libra, and vice-versa.

Preparatory to the study of eclipses, we must first find the dimensions of the shadows of the earth and moon. This is effected by simple geometry. But as some of the elements which we have to consider are variable between certain limits, all we can here expect to do is to get an average estimate, and accordingly very great accuracy is not a necessity.

As no angle with which we are concerned in the investigation is greater than 33′ or a little upwards, we can use the formula $s = r\theta$ wherever required without sensible error, and we may safely look upon an arc of 33′ as being a line.

Let S denote the sun's radius, 425000 miles.
E " earth's radius, 3960 miles.
M " moon's radius, 1080 miles.
D " sun's distance, 93,000,000 miles.
d " moon's distance, 238,000 miles.
x " the length of the umbra of the earth's shadow.
x' " the length of the umbra of the moon's shadow.
h " the radius of the umbra of the earth's shadow at the moon's distance.
h' " the radius of the penumbra of the earth's shadow at the moon's distance.

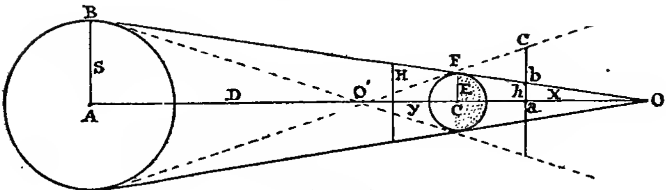


Fig. 65.

In the diagram AB is S, CF is E, CO is x, AC is D, aC is d, ab is h, and ac is h'.

From similar triangles:

$$x : x+D = E : S;\ \text{whence}\ x = D\frac{E}{S-E} \cdots\cdots\cdots (\alpha)$$

Putting M for E in this gives $x' = D\dfrac{M}{S-M}$ .... (β)

Again $h : E = x-d : x$; whence $h = E - \dfrac{d}{D}(S-E)$..... (γ)

And in a similar way by putting y to denote $O'C$ we get $y = D/(S+E)$;

and $h' : E = y+d : y$; whence $h' = E + \dfrac{d}{D}(S+E)$..... (δ)

Putting in the numbers denoted by the letters and performing the arithmetical calculations necessary we get:

$x=874600$ miles, the length of the umbra of the earth's shadow.

$x'=237000$ miles, the length of the umbra of the moon's shadow.

$h=2880$ miles, the radius of the earth's umbra at the distance of 238000 miles away.

$h'=5030$ miles, the radius of the earth's penumbra at the distance of 238000 miles away.

In what follows we shall use the word *shadow* for umbra, as is customary, and where the penumbra is concerned it will be specially mentioned.

We infer: (1) That as the distance of the moon is 238000 miles, and the length of the earth's shadow is 874600 miles, the earth's shadow reaches far beyond the moon's orbit.

(2) That as the radius of the moon is 1080 miles and that of the shadow at the distance of the moon's orbit is 2880 miles, or nearly three times that of the moon, the moon might pass through the shadow and be totally eclipsed for some length of time.

(3) That as the average length of the moon's shadow is 237000 miles, while the distance from the moon to the earth's centre is 238000 miles, the point of the moon's shadow does not reach to the centre of the earth by 1000 miles, but it reaches nearly 3000 miles beyond that surface of the earth which faces the moon.

Of course, these numbers are means or averages. When the moon is in perigee the apex of the moon's shadow reaches about 13000 miles beyond the earth's centre; and when in apogee the apex of the shadow lacks about 11000 miles of reaching the earth's surface.

When the moon is at one of the nodes of its orbit it is in the plane of the ecliptic; and if a full moon happens at that time, the sun, the earth, and the moon are in line, with the earth between the sun and the moon, so that the moon must necessarily pass centrally through the earth's shadow and be totally eclipsed. This is represented at *a* in the diagram,

where EE' is the ecliptic; MM', the moon's orbit; the point where these cross, the node; the large circle, a section of the earth's shadow; and the small circle, the moon at the full.

If the full moon happens when the moon is near the node, but not near enough to give a total eclipse, as at b or b', the

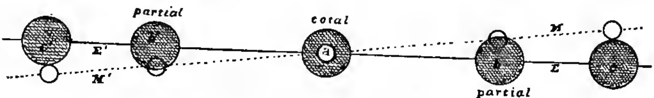


Fig. 66.

moon may cut into the side of the shadow and present us with a partial eclipse. And if the full moon happens still farther from the node, as at c or c', the moon grazes the shadow, but there is no eclipse other than such darkening as may be produced by the penumbra of the earth's shadow. These are the cases of lunar eclipses.

On the other hand, if a new moon happens when the moon is at one of its nodes, the sun, the moon, and the earth are in line, with the moon between the sun and the earth.

So that as seen from some place on the earth, the moon will appear to be centrally imposed on the sun. If the moon is near the perigee it will, for a few minutes, completely hide the sun, thus producing a total solar eclipse at the place of observation. But if the moon is near the apogee it will appear too small to cover the sun, and when centrally imposed will leave a ring of the sun about the dark body of the moon, thus producing an annular eclipse.

The foregoing are general statements as to how eclipses occur. What we have now to do is to consider, in more detail, some particular cases. And from a consideration of the cases of the central eclipse, others can easily be inferred.

61. The Lunar Eclipse.

Let U be a section of the shadow where it is traversed by the moon, P be a section of the penumbra at the same place, and let the small circles denote the moon in six positions in its orbit. These circles should have their diameters as the

numbers 51, 29, and 11. The shadow is at the moon's ascending node, and the moon moves through it from right to left, as seen from the earth.

Position 1. The moon has first contact with the penumbra. As the penumbra brightens rapidly as we pass outwards from the umbra, no visible effect is produced upon the moon until it has entered well into the penumbra, when a hazy and illy-defined darkening becomes observable on the moon's eastern limb, as at *a*.

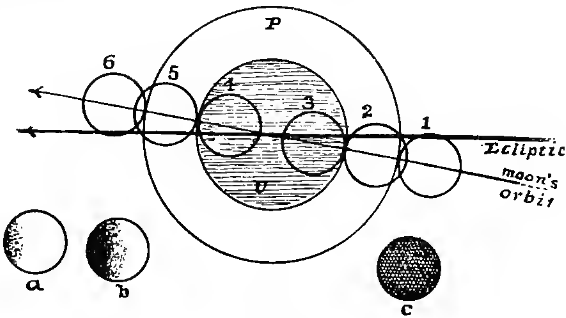


Fig. 67.

Position 2. The limb of the moon has reached the shadow, and the eclipse is said to begin. The darkening on the advancing limb is quite apparent, and its curved outline is readily seen. As the eclipse progresses, the curved black shadow of the earth. with its poorly defined outline, gradually creeps over the surface of the moon, as at *b*. In

Position 3, the whole surface is obscured, and totality begins, as at *c*.

In positions 4, 5, 6 we have but the phenomena of 1, 2 and 3 reversed, as the eclipse is passing away.

Even in the midst of totality the place of the moon is not lost, as it is seen to shine with a faint coppery light sufficient to make its position visible. This effect is due to the earth's atmosphere. The light of the sun which penetrates the atmosphere and passes near the earth is affected in two ways; first, the more refrangible blue violet rays are filtered out and

absorbed in undue proportion, and second, the reddish rays, which succeed in passing, are refracted inwards so as to traverse the distant parts of the umbra, and these, falling upon the moon, give to it its faint and weird illumination. As seen from the moon under these conditions the earth would be surrounded by a narrow halo of ruddy light.

62. Duration of a Lunar Eclipse.

The eclipse may be of any duration from nothing, when the moon just grazes the shadow, to the maximum when the moon passes centrally through the shadow. We shall consider the latter case only.

It is necessary first to find the velocity of the moon relatively to the shadow, that is, to find how fast the moon approaches or leaves the shadow.

As the moon gains one revolution on the shadow in one lunation, or $2\pi \times 238000$ miles in 29.5306 days, a little calculation will show that the moon's relative velocity is about 35 miles per minute.

(1). The distance from the centre of 1 to that of 6 (Fig. 67) is 12220 miles, and at 35 miles per minute the moon passes over this in 350^m, nearly, or $5^h\ 50^m$. And this is the average time between the first and the last contacts with the penumbra.

(2). The distance between the centres of 2 and 5 is 7920 miles, which divided by 35 gives 226^m, or $3^h\ 46^m$. And this is the whole duration of the eclipse, if we regard the eclipse in relation to the umbra only, as is usually done.

On account of the indefinite boundary of the umbra, however, it is difficult to say practically just when the eclipse begins and when it ends.

(3) The distance between the centres of 3 and 4 is 3600 miles, and divided by 35 this gives 103^m, or $1^h\ 43^m$, which is the average length of totality, for the central lunar eclipse.

63. The Solar Eclipse.

The phenomena attendant upon a solar eclipse are considerably different from those of the lunar eclipse, because

of the difference in the points of view of the observer in the two cases.

In the lunar eclipse the observer is situated upon the body that casts the shadow, while in the solar eclipse he is placed upon the body upon which the shadow falls.

In other words, in the lunar eclipse the watcher looks at the shadow as it passes over the face of the moon, while in the solar eclipse the shadow passes over him and hides, either partially or totally, the sun from his view.

To completely harmonize the two the solar eclipse should be viewed from the moon, and we shall adopt this supposition in our illustration.

We have seen that when the moon is near apogee its umbra does not reach to the surface of the earth, and the moon is too small in angular diameter to cover the sun, so that we can have only an annular eclipse of the sun.

For this reason, and for greater generality, we consider the moon to be in perigee, at the distance 225000 miles from the earth's centre, or thereabouts.

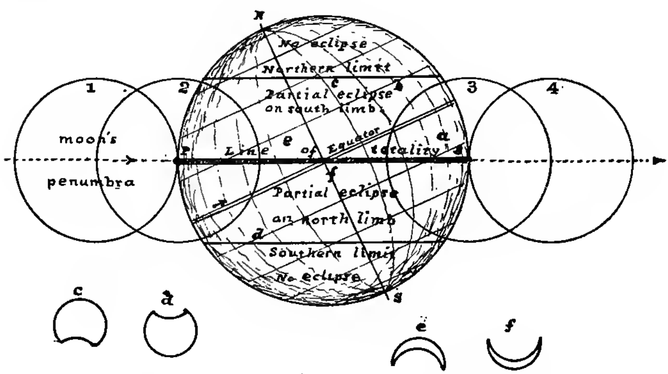


Fig. 68.

By a comparatively easy investigation we find the radius of the penumbra of the moon's shadow, at the position of the

earth, to be about 2120 miles, and the radius of the umbra to be about 70 miles.

If the moon were in apogee the radius of the penumbra would be over 2200 miles, and there would be no umbra.

Draw a circle with radius 57 to represent the earth, and mark the equator and the poles. Through the centre draw an indefinite line, inclined to the earth's axis at any angle greater than about 62°, to represent the moon's orbit, and consequently the path of the centre of the moon's shadow. On this as a line of centres draw the circles 1, 2, 3, 4, as in the diagram, with a common radius 30, to represent four positions of the penumbra; and at the centres of these the black dots, with radius 1, to represent the umbra of the moon's shadow.

As seen from the moon the shadow moves from left to right across the earth, and the earth turns in the same direction. Thus every solar eclipse comes in from the west and moves eastward or nearly eastward across the earth.

Position 1. The penumbra touches the earth at *r*, and the eclipse begins on the earth, since to a person at *r* the limb of the moon has just come into apparent contact with that of the sun. At *r* the sun is on the eastern horizon and is rising so that here the eclipse begins at sunrise.

Position 2. The umbra has come into contact with the earth, and to observers now at *r* the total eclipse is beginning at sunrise.

Position 3. The umbra has arrived at *s*, which has the sun on the western horizon, and the total eclipse begins at sunset. And finally the penumbra leaves the earth at position 4, that is, the eclipse ends at sunset, or to the observer at *s* the moon has completely withdrawn from hiding any part of the sun.

The penumbra, in its course, traces out a kind of belt across the surface of the earth, and every place that lies within this belt when the penumbra reaches the place will witness an eclipse of the sun, while to places outside this belt there will be no eclipse.

But it does not follow that every place that is within the

belt when the eclipse begins at *r* will have the eclipse. For, as the earth is rotating in the same direction as that in which the shadow is moving, a place situated as *a* will have 'turned the corner' and passed into the night before the eclipse arrives; and a place as *b* may have been carried out of the belt across the northern limit.

To a place situated as *c* when the penumbra overtakes it there will be a small eclipse on the sun's southern limb, as represented at *c* in the diagram; to a place situated as *d*, a small eclipse on the sun's northern limb; at *e* the eclipse will be large on the southern limb, and at *f* it will be large on the northern one.

And finally all places so situated as to be in the narrow belt of totality, when the eclipse comes along, will witness a total eclipse of the sun.

If the moon were in or near apogee there would be no belt or line of totality, but those situated along the middle line of the penumbra's path would be visited with an annular eclipse of the sun, as at *Z*, figure 64.

The path of a central eclipse may be inclined to the equator at an angle as high as 28° 33′, as in the diagram, where the eclipse is represented as taking place at the time of the autumnal equinox. If the eclipse happens at the time of a solstice, it may begin and end on the equator, but as the equator, seen from the moon, is then projected into an ellipse, the central line of the eclipse will pass above or below the equator according as it is the summer or the winter solstice.

64. Duration of Central Eclipse of the Sun.

The distance from the centre of 1 to that of 4, (Fig. 68), is about 12160 miles, and as the shadow moves practically with the same velocity as the moon, 35 miles a minute, this distance is travelled in 348^m, or $5^h\ 48^m$, which is the total duration of the eclipse, for the whole earth, from its beginning to its end.

With the moon in apogee the motion of the shadow is slower and the penumbral circle is larger, so that the total length would be increased by 6 or 8 minutes.

The longest duration of the eclipse at any one place on the earth is for places situated near the centre of the earth's enlighted disc at the time. For such places are being carried by the earth's axial rotation, at the rate of 17 miles a minute, in a direction nearly coinciding with that of the shadow. So that the shadow gains only 18 miles a minute. And 4240 miles, the diameter of the penumbral ring, divided by 18 gives $3^h\ 56^m$ for the maximum duration of the eclipse at one place. And this would be lengthened out a few minutes with the moon in apogee, as already pointed out.

The rate of 17 miles a minute is for places on the equator; if the central line of the penumbra passes north or south of the equator, the eclipse will not last quite so long.

65. Duration of Totality.

The diameter of the umbral ring upon the earth is, at the best, only about 140 miles. And 140 divided by 18 gives less than 7 minutes for the duration of totality under the most favorable circumstances.

If the moon is near one of the nodes of its orbit, but not at it, at the time of new moon, the eclipse will not be central, but will pass over the northern part of the earth, or over the southern, as circumstances determine. And when the new moon happens sufficiently far from the node that only a part of the penumbra meets the earth, the eclipse will be a partial one visible only in high northern or southern latitudes, as the case may be.

When we consider that the moon's penumbra, as also the umbra, is a cone which sweeps over a revolving sphere, we can readily understand that the path of the shadow over the earth will be bounded by a somewhat complex curve in the case of even a central eclipse, and by a still more complex one in that of a partial eclipse.

In the British Ephemeris or Nautical Almanac these curves are calculated and plotted for every solar eclipse of the year.

We present herewith maps of the courses of the eclipses for May 28th, 1900, and December 31st, 1880, as these prove to be two quite characteristic ones.

In I, both the north and the south limits of the eclipse are shown, the north one passing near the pole, and the eclipse is confined to the northern hemisphere, except for a

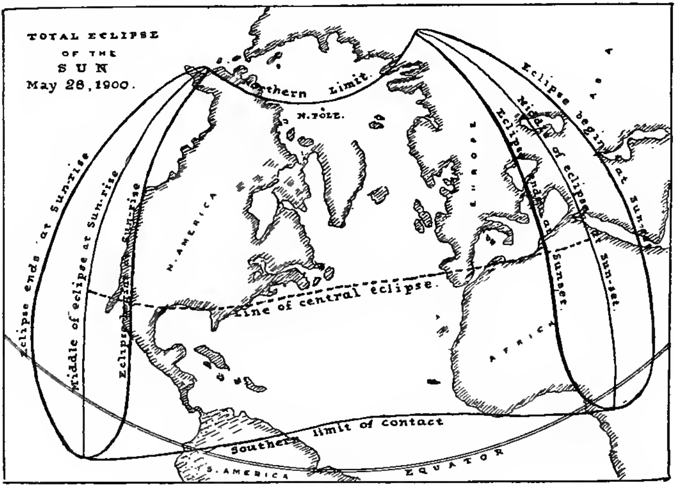


Fig. 69 I.

little at the beginning. Totality begins in the Pacific Ocean, at a little west of Lower California, at which place the sun is then rising, and it ends in Egypt, at which place and time the sun is setting. The belt of totality is quite narrow, but wider at the middle than at the extremities, as these latter points are nearly 4000 miles farther from the moon than the middle part of the belt is. For as the moon's umbra is a cone with its apex towards the earth, its section becomes smaller as we recede from the moon. The eclipse was visible over the whole of North America and Europe, over a small portion of South America and a limited portion of western Asia. On May 28th the north pole was somewhat inclined towards the sun, and the eclipse reached northwards to a point beyond the pole.

In II, the point A is near the Arctic Circle, and the earth's axis, leaning away from the sun, this point is the most northern limit of the sun's rays at this date. The umbra passes north of the earth without touching it, so that the eclipse is partial only. The loops crossing at A show the angle through

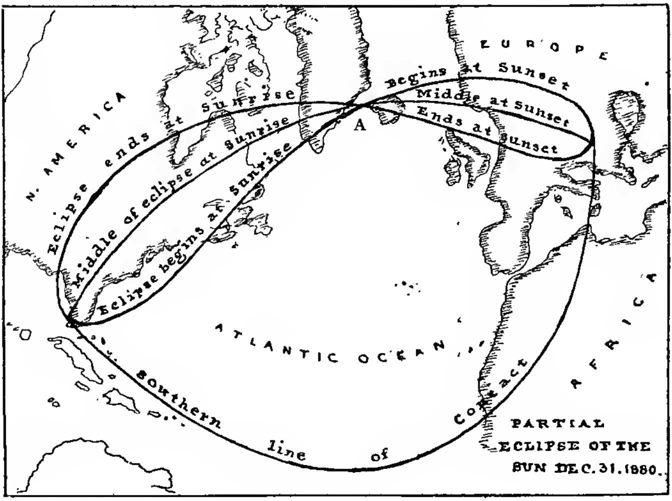


Fig. 69 II.

which the earth turns while the penumbra is passing over it.

The calculation and plotting of these curves for any particular eclipse is a matter of some difficulty, and beyond the scope of this work, but the comprehension of what the curves mean should not be difficult.

66. Occurrence of Eclipses.

An eclipse of the moon can take place only at the time of full moon, and an eclipse of the sun only at the time of new moon. And yet it is well known that eclipses do not happen at every full and new moon. For there are 12 full moons

and 12 new moons in every year, while the average number of eclipses in a year is only 4.

Our present purpose is to examine the conditions under which eclipses take place and the order of their presentation.

The Lunar Eclipse. It would be of little service to investigate the conditions under which the moon first meets the penumbra of the earth's shadow, for, as already stated, the moon must dip to a very considerable extent into the penumbra before any visible effect is produced upon the limb of the moon.

Hence it is usual to consider a lunar eclipse in relation to the umbra only, so that the eclipse begins when the moon first comes into contact with the umbra of the shadow.

On account of the variations in the distance and velocity of the moon the results arrived at must be looked upon as approximations which admit of variations within small limits.

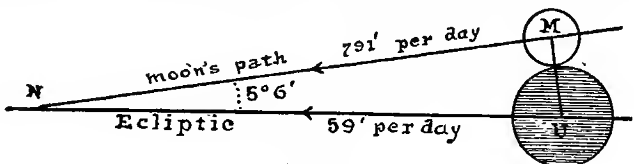


Fig. 70.

Let U be the centre of the earth's shadow (umbra) moving along the ecliptic in the direction UN, and let M be the centre of the moon moving along its orbit MN, and so situated at the particular moment that it just touches the shadow externally, as illustrated. Then N is the moon's descending node, and the distance NU is called the *lunar eclipse limit* on one side of the node, because a lunar eclipse can happen only when the distance of the centre of the shadow from the node is less than the eclipse limit UN.

Now UM is $2880+1080=3960$ miles; and UN is $UM\times$ cosec $5°\ 6'=44550$ miles; and this is one-half the lunar eclipse limit in miles. But we wish to have it expressed in days, that is, in terms of the motion of the shadow per day. As the shadow moves over the moon's orbit in 365 days, the

motion per day is got from $2\pi\times238000/365$, or 4100 miles, nearly. And 44550/4100 gives 11 days to the nearest day.

But the sun is directly opposite the shadow and is the same distance from one of the nodes as the shadow is from the other.

Hence, if the shadow, or, what is equivalent, the sun, is more than 11 days from a node at the time of full moon, no eclipse of the moon takes place; and if the distance of the sun from a node be less than eleven days when the moon is full, the moon will be eclipsed either partially or totally.

Again, when the moon touches the umbra internally we have the beginning of totality. The distance between the centres of moon and shadow is now $2880-1080=1800$ miles, and making a calculation similar to the last we obtain 5 days to the nearest day. So that the lunar eclipse will be total if the sun is within five days of one of the nodes at the time of full moon.

And thus the whole lunar eclipse limit is 11 days on each side of the node, or 22 days in all; and the total eclipse limit is 10 days in all.

67. Solar Eclipse.

By making U the centre of the earth and M the centre of the moon's penumbra, we find, by a process perfectly analogous to the one applied in the case of the lunar eclipse, that the *solar ecliptic limit* is 17 days on each side of the node, or 34 days in all.

So that if a new moon happens when the sun is within 17 days of a node, there will be a solar eclipse at some place upon the earth. And if the new moon happens when the sun is more than 17 days from a node, there can be no eclipse at that new moon.

Another Method.

The foregoing method of studying the occurrence of eclipses by means of linear measures expressed in miles is very explicit and easily understood, and is probably the best for illustration. But in practical work a modification, in which linear measurements are replaced by angular ones, is

found to be more convenient, as these angular quantities, with their daily variations, are tabulated in the almanac.

Thus, if P denotes the moon's horizontal parallax; p, the sun's horizontal parallax; s, the sun's angular semi-diameter; m, the moon's angular semi-diameter; and u be the angular diameter of the radius of the earth's umbral circle at the distance of the moon, we have

$$P=E/d;\ p=E/D;\ u=h/d.$$

And by substituting in (γ) of page 117 we get

$$u=P+p-s.$$

But if at full moon the moon touches externally the umbral ring in its passage, the distance of the moon's centre from the ecliptic, that is, the moon's latitude, is practically $u+m$. So that if l denotes the moon's latitude, we have

For external contact $l=P+p-s+m$.

Similarly " internal " $l=P+p-s-m$.

We can accordingly state that:

At any full moon there will be a lunar eclipse if the moon's latitude is less than $P+p-s+m$; and the eclipse will be total if the latitude is less than $P+p-s-m$.

The letters denote angles in radian measure, but the equation is equally true when the angles are given in degree measure.

By a similar process of reasoning we find for a solar eclipse: At any new moon there will be a solar eclipse upon some part of the earth if the moon's latitude is less than $P-p+s+m$; and the eclipse will be total or annular at some places on the earth if the moon's latitude is less than $P-p+s-m$.

These quantities do not vary much, and p being only 8″.8 may be ignored unless great accuracy is required.

The average values of the others in minutes of angle are: $P=58'$, $s=16'$, $m=16'$.

Illustration 1. At the full moon on January 22nd at $1^h\ 46^m$ past midnight, 1880, the moon's latitude was about 48″ south. And as this is well within the limit for total eclipses, which is about 26′, there was a large total eclipse of the moon, it being nearly central.

Illustration 2. The new moon of November, 1882, happened at $11^h\ 9^m\ 6^s$ after mean noon at Greenwich, and the moon's latitude at the time was 35′ 22″ south. But the limit for totality in a solar eclipse is 58′. And there was an eclipse on the southern hemisphere. The eclipse was annular, and visible in Australia and the South Pacific islands.

In the British Nautical Almanac, the moon's latitude is given for noon and midnight on every day of the year, and is easily found for any specified time.

68. Eclipse Periods.

We have seen that an eclipse can happen only at new moons and full moons, and then only when the sun is within a given distance from one of the moon's nodes, 17 days from the node in the new moon and a solar eclipse, and 11 days from the node in the case of the full moon and the lunar eclipse. And as the sun passes each node once in a year, we have two periods in the year at which eclipses can take place, or *eclipse periods*. The lengths of these periods are 34 days for solar eclipses and 22 days for lunar eclipses.

As the time elapsing between two consecutive new moons is not quite 30 days, we see, at once, that there may be two solar eclipses at the same eclipse period.

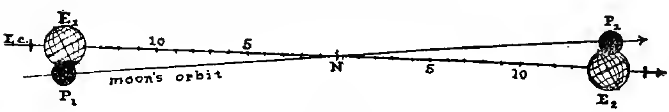


Fig. 71.

This is illustrated in the diagram, which represents matters as seen from the moon. N is the moon's ascending node, and the ecliptic is marked off into days, that is, each division represents one day's motion of the earth in its orbit. E_1 is the earth at 15 days before reaching the node, and E_2 is the earth 30 days later, both being within the eclipse limit of 34 days. Let a new moon happen when the earth is at E_1 and let P_1 be the moon's penumbral circle; then a second new moon will take place at E_2 with P_2 as the penumbral circle.

The first eclipse is at the south polar regions, and the second one at the north polar regions.

If these conditions occur at the descending node, matters are reversed in the way that the first eclipse would be at the north polar regions and the second at the south polar regions.

But in either case when two solar eclipses happen at the same eclipse period, they are both small and are confined to polar latitudes.

As there is a full moon just half-way between two consecutive new moons, the moon will be full at the node opposite that at which the new moon takes place, and there will be a total lunar eclipse.

Thus, then, *when there are three eclipses at the same eclipse period, two will be small eclipses of the sun visible at polar latitudes, and the third a total eclipse of the moon.*

As the lunar eclipse limit is only 22 days, it is evident that there cannot be two lunar eclipses at the same period, and that there need not be any.

Also, as the limit of totality of a lunar eclipse is 5 days on each side of the node, if there be a partial eclipse of the moon at a period the moon must be more than 5 days from the node, and there can be only one eclipse of the sun, and therefore only two eclipses altogether at that period.

So that *when there are two eclipses at the same eclipse period, they will be a partial eclipse of the moon or a total one of short duration, and an eclipse of the sun.*

Finally, if there be a solar eclipse less than 4 days from the node, there can be no lunar eclipse at that period.

Therefore, *if there be only one eclipse at a period it will be a nearly central eclipse of the sun.*

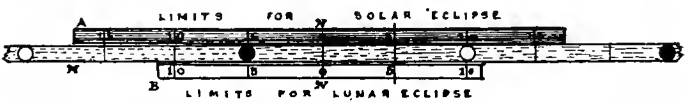


Fig. 72.

All of these may be illustrated by the accompanying diagram.

Take three graduated rules *A, M, B, A* being 34 units long, *B* 22 units, and *M* of indefinite length, the unit being the same for each. The open circles are 30 units apart, and a black circle is half-way between two open circles. The black circles are referred to scale *A* only, and the open circles to scale *B*. Then by sliding *M* between *A* and *B* all the preceding cases of eclipses at a node may be illustrated. Thus it is seen that it is possible to make two black circles (new moons) fall within the limits of *A*, and then the intermediate white circle will be near *N*. But it is impossible to bring two white circles to lie within the limits of *B*, etc.; showing that there may be two small solar eclipses and a total lunar eclipse at one eclipse period. But there cannot be two lunar eclipses at the same eclipse period. In like manner all the other cases are illustrated.

69. Motion of Moon's Nodes.

The nodes of the moon's orbit retrogress at the rate of one revolution in 18.6 years. And as the sun progresses at the rate of one revolution per year, we see that the sun will pass from a node around to the same node again in $(18.6\times1)/(18.6+1)$ years, or 346 days to the nearest day. And hence the time required for the sun to go from one node to the other node is 173 days.

But six lunations occupy 177 days, and thus the time required for the sun to pass from the one node to the other is 4 days less than that required for six lunations.

So that if a new moon happens when the sun is exactly at one of the nodes, giving a central solar eclipse, the sixth new moon thereafter will occur when the sun is 4 days past the other node, and there will be another solar eclipse, nearly central.

After another term of six lunations there will be another solar eclipse, with the sun 8 days past the node, and thus, as yet, far within the solar ecliptic limit.

These relations give rise to a peculiar periodicity of eclipses which we shall briefly consider.

The figure represents portions of the moon's orbit, or of the ecliptic, about the moon's nodes, the extent of each portion being such as to include the solar limits of 17 days on each side of the node. These are divided into parts representing 4 days each, from 16 days before the node to 16

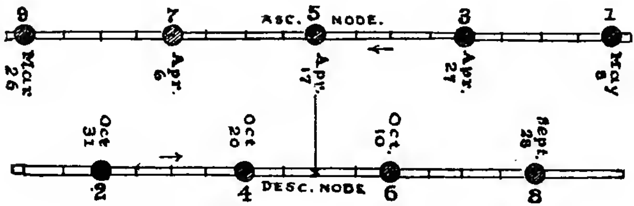


Fig. 73.

days after. The dates given, and the relative positions of the eclipses laid down might occur at some time, but for the present are merely explanatory.

Suppose that a new moon happens on May 8th, 16 days before the sun reaches the ascending node. This will be a small eclipse visible in the Antarctic regions. This is eclipse number 1.

The next new moon after six lunations is on October 31st, with the sun 12 days before reaching the descending node, and the eclipse is a small one confined to northern regions of the earth. This is eclipse number 2. Another six lunations gives us eclipse number 3, with the sun 8 days in front of the ascending node. This eclipse is on April 27th, and is visible over southern temperate regions.

Eclipse number 4 occurs on October 20th, with the sun 4 days before the descending node. This will be visible over a large part of the earth, with its centre line north of the equator. The next eclipse, number 5, with the sun at the ascending node, happens on April 17th, and the eclipse will be central over the earth.

In a similar way eclipses 6, 7, 8, 9, occurring on October 10th, April 6th, September 28th, and March 26th, may be accounted for.

We notice from the foregoing: 1st, That the solar eclipse which began as number 1 on May 8th reappeared alternately at each node, moving forwards 4 days at each appearance. until it finally passed away with its ninth appearance on March 26th, nearly four years after its first presentation.

Eivdently these nine eclipses do not include all the solar eclipses happening in the period, as there must have been a small solar eclipse about November 1st corresponding to the one on May 8th, etc., but these nine, by their orderly advance of 4 days at each occurrence, form a natural group, and lead one to look upon the whole series as being recurring presentations of one and the same eclipse. So that, with this view, eclipses, like human beings,

"Have their day and cease to be."

Every solar eclipse, then, begins when the sun has fairly entered upon the western border of a solar limit at one of the nodes. It then travels eastwards through the limits alternately at each node, until after 8 or 9 presentations it passes off into space, and is succeeded by another.

And the same may be said of a lunar eclipse, except that, on account of the shorter limits, the number of presentations will not exceed 5, and may be only 4.

We notice, 2nd, that the eclipse periods travel backwards through the year, which is, of course, due to the retrogression of the moon's nodes.

70. Number of Eclipses in a year.

In the case of a central solar eclipse there can be no eclipse of the moon at that period. So, if the periods come in not at the beginning or end of the year, we may have a solar eclipse with the sun a couple of days in advance of the node, and at the next period another solar eclipse with the sun two days past the node. And thus the least number of eclipses in the year is two, and they are both of the sun and quite central over the earth.

If the eclipse period begins with the year, so that there may be a small solar eclipse on January 1st or 2nd, there may

be three eclipses at this period, two of the sun and one of the moon. At the next node, 173 days after, we may have three more eclipses, two of the sun and one of the moon. Then, after 346 days, which is 19 days before the year closes, the first node comes in again in time to give another eclipse of the sun before the end of the year.

And thus the greatest number of eclipses which can take place in any one year is 7, of which 5 are solar and 2 lunar.

The most common number of eclipses in a year is 4.

71. The Saros.

This is a remarkable cycle in the recurrence of eclipses which has been known since very early times and whose discovery has been, by some ancient writers, attributed to the old Chaldean astronomers.

The occurrence of an eclipse depends, as we have seen, altogether upon the relative positions of the moon and the nodes of the moon's orbit at the time of new or full moon. If the moon and the node were exactly together at any new moon, and if after n lunations the moon and the node were again exactly together at the new moon, they would presumably be exactly together after every period of n lunations, and every eclipse of one of these cycles of n lunations would be repeated in each and every cycle, so that a record of the eclipses for one cycle would answer for every cycle so far as the sequence and magnitudes of the eclipses were concerned.

If this correspondence were not exact, but very approximately so, the character of the set of eclipses belonging to one cycle would differ only slightly from that of those belonging to the preceding cycle, and although there would be a slow and gradual marching of the eclipses through the cycle, it might require many years to effect a very material change in the main features of the eclipses belonging to the set.

Now, the moon's siderial period is 27.32166 days, while the node makes one revolution backwards in 6793.39108 days. Hence, we find, by the formula $ab/(a+b)$, that the

time required by the moon to pass from one node to the same node again is 27.21222 days. And we know that the length of a lunation is 29.53059 days.

Hence $223 \times 29.53059 = 6585.322$ days,

and $242 \times 27.21222 = 6585.357$ days.

Or, the time required for 223 lunations is shorter than that required for 242 returns of the moon to the same node by only 0.035 days. And as the moon moves $13^{\circ}.2$ per day, this is equivalent to about 28′, or 4′ less than the moon's diameter.

So that if a new moon happened in any year exactly at the node, the 223rd new moon after would take place when the moon was 4′ less than its diameter from the node, and the two eclipses would be almost exactly alike in magnitude.

But this is not all. The perigee makes one complete revolution forwards in 3232.5753 days. Then we find that it takes the moon 27.5546 days to go from the perigee to the perigee again. And 239×27.5546 is 6585.534 days, which differs from 223 lunations by only 0.212 days, or an angle equal to about 2° 48′ or about 5 times the moon's diameter. So that if a solar eclipse happened when the moon was in perigee, the 223rd new moon thereafter would have the moon only 5 times its own diameter from the perigee, and the two solar eclipses would be almost exactly of the same character as to their being total or annular.

Thus we have 223 lunations, 242 returns to the same node, and 239 returns to the perigee occupy almost the same length of time.

Dividing 6585.322, the number of days in 223 lunations, by 365 gives 18 years of 365 days each, with $15\frac{1}{3}$ days over very nearly. But 18 years contain either 4 or 5 leap years, and taking the 4 or 5 days from the $15\frac{1}{3}$ gives us 18 yrs. $11\frac{1}{3}$ days, or 18 yrs. $10\frac{1}{3}$ days, according as there are 4 or 5 leap years in the cycle. So that a new Saros begins only $10\frac{1}{3}$ or $11\frac{1}{3}$ days later in the year than the preceding one did, and the corresponding eclipses of two consecutive Saroses will take place in practically the same parts of the heavens. that is, in positions only 10° or 11° removed from the places of the former.

The number of eclipses in a Saros is about 70, of which 40 are solar and 30 lunar.

Although the Saros offers a remarkable relation as existing among the times of three particular revolutions, the moon, the node, and the perigee, yet the small discrepancies existing gradually and slowly carry those eclipses which are near the border from one cycle into the next.

72. The Metonic Cycle.

We ask, is there any cycle of years such that the new moons or full moons will repeat themselves, so as to fall upon the same dates in the year? Or if there is no exact cycle of this kind, what is the closest approximation we can find to it?

The equinoxial year=365.2422 days, and the mean lunation is 29.5306 days. By forming a fraction with these numbers and finding its convergents, we get 19/235 as a very close approximation. Or, in other words, 235 lunations are approximately equal to 19 equinoxial years.

Now $19 \times 365.2422 = 6939.602$ days,
and $235 \times 29.5306 = 6939.690$ days.

These differ by only 0.088 days or about $2^h\ 6^m$. Thus, if a new moon occurred at mean noon on January 1st in any year, the 235th new moon thereafter would happen in the 19th year thereafter on January 1st at about $2^h\ 6^m$ p.m., not considering the variation due to leap years. So that, practically, the new and full moons of any year occur upon the same days of the same months as they did 19 years before. This cycle of 19 years was discovered by Meton, a Greek astronomer, about 433 B.C., and after him it is called the *Metonic Cycle.*

The cycle is of some importance in chronology as far as its facts have relation to the motions and places of the moon; but as the years are counted as 365 days with the necessary addition of a day every four years, the times of the moon's changes as given by the Metonic Cycle may be as much as a whole day off at certain times, or under certain circumstances. With these unimportant discrepancies, the moons

of one cycle are repeated in the next cycle with remarkable faithfulness, when the whole case is considered.

But the Metonic Cycle, unlike the Saros, has no practical connection with the recurrence of eclipses.

ECCLESIASTIC CALENDAR.

This article is inserted here, not because of its astronomical importance, but because it has a relation to our civilized life, which must make it of considerable interest to many people.

The moveable feasts of the ecclesiastic calendar are dependent upon Easter, which itself is dependent upon a special full moon. Thus, Easter Sunday is the first Sunday following the ecclesiastic full moon which happens first after the vernal equinox. So that Easter may fall any time between the 23rd of March and the 26th of April.

By the ecclesiastic full moon is meant, not the full moon of the astronomer, but the average full moon, so to speak, as determined by means of the Metonic Cycle or a modification of it. This is necessary if Easter is to be kept upon the same Sunday throughout the Christian world. For it is easily conceivable that an astronomic full moon may occur at one place on a Saturday and at some distant place upon the Sunday after. And in such a case the "Sunday following the full moon" would not be the same for both places.

That is, the ecclesiastic full moon is not an absolute event for the whole earth, as the astronomic full moon is, but has relation to the local time.

The determination of Easter, then, fixes the moveable feasts for the year, and for this determination we make us of the *Golden Number*, the *Epact* and the *Sunday letter* or *number*.

73. The Golden Number.

The Golden Number for any year is the number of that year in the Metonic Cycle of 19 years, and it received its name from the circumstance that it was formerly printed in the calendar in figures of gold.

The beginning of the cycle is arbitrary, but usage has given us the following rule:

Denote the golden number by G, and the year by y.

Then G is the remainder from $(y+1)/19$. And if there is no remainder the golden number is 19, as zero does not count. Thus the golden number for 1910 is 11.

74. The Epact.

This has been already explained as the moon's age on January 1st, or the number of days which have elapsed on January 1st since the previous new moon.

If we know the epact, E, for any year, we can readily find the dates of all the new and full moons of the year. But as the new moons repeat themselves every 19 years, so the epact must have a cycle of 19 years, and should be determinable from the golden number. We have the following rule:

The remainder from $11(G-1)/30$ is $E+1$, or E, according as the year is a common year or a leap year.

Thus for 1910, which is a common year, $11(11-1)/30 = E+1 \quad \therefore E=19$, the epact for 1910.

Having the epact we can calculate the date of the full moon following the vernal equinox. Thus for 1910 the epact is 19. Taking this from 30 leaves 11th for date of new moon in January. Adding 59 (two lunations) to 11 and subtracting 31+28 for January and February leaves 11th for date of new moon in March. And adding 14 we get March 25th as the date of full moon in March. This is after the vernal equinox, and the Sunday following this was Easter.

75. The Dominical or Sunday Letter.

This is a letter, from A to G, accompanied by a number and a day of the week, and indicates the date of the first Sunday in the year.

The rule for finding the Sunday number is as follows:

The division $(5y+19)/4$ gives $Q+$a remainder.

Then $7-$Remainder from $Q/7=$the Sunday number $=$the date of the first Sunday in the year. When the number comes out zero, 7 is to be taken.

Applying this to 1910 gives 2, so that January 2nd was Sunday, and the year came in on Saturday.

Thence it is easy to find that March 27th was Sunday, and, from the foregoing, Easter Sunday.

The numbers, the letters and the days of the week are connected as follows:

1	2	3	4	5	6	7
A	*B*	*C*	*D*	*E*	*F*	*G*
Sun.	Sat.	Fri.	Thur.	Wed.	Tues.	Mon.

Thus the Sunday letter for 1910 is *B*, and the year began with Saturday. The Sunday letter for 1915 is *C*, and the year begins with Friday, and the first Sunday is the 3rd.

In leap years the Sunday letter retrogrades one place after February 29th, on account of the additional day in February. Thus, for 1912 we have *G* from January 1st to March 1st, and then *F* for the rest of the year; so that the Sunday letters are *GF*.. That is to say, that after March 1st, the Sundays follow the same order as if the year began with Tuesday instead of with Monday.

The following stanza is often convenient in connecting certain days of the months with the first day of the year:

The 1st of October you'll find if you try,
The 2nd of April as well as July,
The 3rd of September and also December,
The 4th day of June and no other remember,
The 5th of the leap-month, of March and November,
The 6th day of August and 7th of May
Agree with the first in the name of the day.
But do not forget that when leap year is reckoned
From the first of March on they agree with the second.

Thus, in 1910 the 3rd of December is Saturday, and the 24th is Saturday, so that Christmas is on Sunday.

76. The Julian Calendar.

The Julian Calendar, which was devised by an Egyptian astronomer, Sosigenes, under the patronage of Julius Caesar, and hence named after him, made three successive years to consist of 365 days each and the fourth year of 366 days.

This is the same as the present, or Gregorian, calendar, with the exception of the correction for centuries, and introduces an error of 3.104 days in 400 years.

At the time of the Council of Nice, 325 A.D., the vernal equinox was on March 21st, but in the reign of Pope Gregory XIII, 1582, the vernal equinox had shifted to March 10th. By the advice of the astronomers of the time the pontiff issued a decree that the day after the fourth of October in that year should be called the fifteenth, thus throwing 10 days out of the calendar of the year.

This change was adopted at once in all Roman Catholic countries, but it was not adopted in Great Britain until the year 1752, when by Act of Parliament 11 days were thrown out between the 2nd and the 14th of September. Russia adopted the changed calendar only about two years ago.

In reading dates one often finds them distinguished as O.S., old style, and N.S. new style, these having reference to the change in the calendar. O.S., then, means according to the Julian Calendar, and N.S., according to the Gregorian Calendar.

THE SOLAR SYSTEM.

The members of the solar system are: (1) the sun, which is the practical centre of the system and the principal source of its light and heat; (2) a number of planets and planetoids or asteroids revolving about the sun and retained in their orbits mainly by the sun's attraction; (3) a number of moons, or secondary planets, which revolve about certain of the planets as centres; and (4) an indefinite number of comets or cometary and meteoric masses which manifest their presence only occasionally.

The principal planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. The planetoids or asteroids differ from these principally in regard to size, they being comparatively very small. Thus the diameter of the smallest planet is nearly 3000 miles, while that of the largest

planetoid is probably not 300 miles, and some of them are very much smaller.

The principal known planetoids are Eros, a small body circulating between the orbits of Earth and Mars, and a group numbering over 300, which have their orbits lying between those of Mars and Jupiter.

The planetoids are all telescopic on account of their small size, and the majority of them can be seen only under high powers of the telescope. Also, two of the known planets, Uranus and Neptune, are telescopic, but not on account of their small size, as they are both large planets, but on account of their great distance. And recently a telescopic planet has been discovered beyond the orbit of Neptune, but nothing very definite is, as yet, known about it. However, whatever its real size may be, it cannot be small and be visible at such a distance.

77. Order of the Planets.

The accompanying list gives the order of the planets, counted from the sun outwards, together with the astronomical symbols by which they are denoted, when there are such. Those numbered are principal planets:

1. Mercury,	☿	Asteroids,	
2. Venus,	♀	5. Jupiter,	♃
3. Earth,	⊕	6. Saturn,	♄
Eros,		7. Uranus,	♅
4. Mars,	♂	8. Neptune,	♆

Of the first four planets, Mercury, Venus, Earth, and Mars, the largest is the earth, with a diameter of 7920 miles, and of the next four, Jupiter, Saturn, Uranus, and Neptune, Uranus is the smallest, with a diameter of nearly 35,000 miles.

So that the planets are readily divided into four minor ones, which lie near the sun, and four major ones, which lie farther away. This great difference in the sizes of the minor

and major planets is a peculiarity of which there is no ready explanation.

Eros is a small body, probably not more than 8 or 10 miles in diameter, and the numerous asteroids vary in size from about 300 miles down to 4 or 5 miles in diameter. These are of very little interest to any one except the professional astronomer, and not of much interest to him; although it is thought that Eros may be of some importance in correcting the present accepted distance of the earth from the sun.

78. Common Statements for the Planets.

(1). All the planets and planetoids revolve in ellipses approximately circles, having the sun at one of the foci, and all the moons revolve in ellipses having a primary planet at one of the foci.

(2). All the planets and planetoids revolve in the same direction, such that, as seen from the northern pole of the ecliptic, it is opposite to that of the hands of a clock over the dial. This is called the positive direction, and all the moons, with one exception, revolve about their primaries in the same positive direction.

(3). Every planet that rotates on its axis does so in the positive direction.

(4). All the planets have orbits which are confined to the zodiac, and some of them lie quite close to the ecliptic.

But this is not true of the planetoids, as about 30 per cent. of them stray beyond the confines of the ecliptic.

This community of properties naturally points to a community of origin, and the probability is that in some way, the nature of which is not certainly determined, the sun and the planets have come, by a natural process of evolution, from something which preceded them in time, and which was the common origin of them all.

It follows, from what precedes, that the orbit of every planet crosses the ecliptic at two points, and thus has an ascending and a descending node; so that every planet is, generally speaking, one half the time upon the northern side of the ecliptic, and one half the time upon the southern side.

The accompanying table of the elements of the planets will be found useful:

Planet	Diam. in miles	Dist from Sun in millions of miles	Dist. from Sun $\oplus=1$	Period of Revol. in dys.	Mean Orbital vel. in miles per min.	Rotation on Axis	Inclination of Orbit	Long. of Ascen. Node	Dens'y
Mercury	3000	35¾	.387	88	1773	88 dys.	7°0′	46°	6.85
Venus	7660	66¾	.723	224.7	1296	225 dys.	3°24′	75°	4.81
Earth	7920	93⅓	1.000	365.3	1102	23.9 hrs.	0°0′	0°	5.66
Mars	4210	141	1.524	687	895	24.6 hrs.	1°51′	48°	4.17
Jupiter	86000	480	5.203	4332	484	9.9 hrs.	1°19′	99°	1.38
Saturn	70500	881	9.539	10760	357	10.2 hrs.	2°30′	112°	0.75
Uranus	31700	1771	19.183	30700	252		0°46′	73°	1.28
Neptune	34500	2775	30.054	60000	202		1°47′	130°	1.15

This table brings into prominence several peculiar features of the solar system.

(1) The very great increase in the sizes of the planets as you pass from Mars to Jupiter, and the corresponding decrease in their densities. Thus, on the average, a cubic foot of the matter which composes any one of the major planets, is not one-fourth as heavy as a mean cubic foot of the material forming the earth; and Saturn is so light that it would float in water.

One would naturally expect the very reverse. For a large planet should have more central attraction of its parts and therefore be more condensed than a small one. And the only feasible explanation is that these major planets are very hot and that a very large proportion of their visible bodies is in a gaseous state, while the solid and liquid matter forms a nucleus in the centre.

We notice also that, with the exception of Mercury, all the principal planets have their orbits lying quite close to the ecliptic, so that their deviations from side to side includes only a small part of the zodiac.

Mercury and Venus have both been stopped in their axial rotation by tidal friction, so that they now present the same

face continually to the sun, or they revolve on their axes in the same time as they revolve about the sun.

79. Relation between Period and Distance of a Planet. Kepler's law III.

Let S be the sun and let the planet at P be moving in the direction PT at right angles to the radius PS, and let its orbit be a circle.

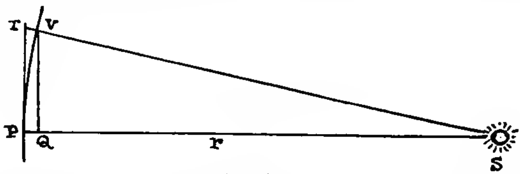


Fig. 74

The attraction of the sun on the planet pulls it in the direction PS, and as the orbit is a circle, PQ may be taken as the measure of the sun's attraction and be denoted by f, while QV, denoted by v, will represent the planet's velocity in its orbit; for however near V is to P the motions PQ and QV brings P to V.

But by an elementary theorem on the circle $PQ(2r—PQ) = QV^2$ And PQ being very small in comparison with PS and QV, its square may be rejected when V is near P, so that at the limit $PQ = QV^2/2r$, or $f = cv^2/r$ where c is a constant.

But if t be the time of revolution about the sun, $v = 2\pi r/t$. And m denoting the mass of the sun, $f = c_1 m/r^2$ where c_1 and m are constants.

Whence eliminating f and v, $r^3/t^2 =$ a constant.

That is, for a planet moving in a circle *the cube of the radius of the orbit is proportional to the square of the time of revolution.* And as all the planets move in orbits which are nearly circles, and their masses are very small as compared to that of the sun, we may make the general statement that with any two planets *the squares of their periodic times are proportional to the cubes of their mean distances from the sun*; and this is Kepler's law III.

80. The Inferior Planets.

This term is applied to the two planets *Mercury* and *Venus*, whose orbits are included within that of the earth. The phenomena attendant upon these planets are somewhat different from those attendant upon the superior planets, or those whose orbits lie beyond that of the earth.

As very little can be said to be actually known of the physical state or condition of any of the planets except the earth, we shall confine ourselves at present principally to mechanical descriptions of movements and appearances.

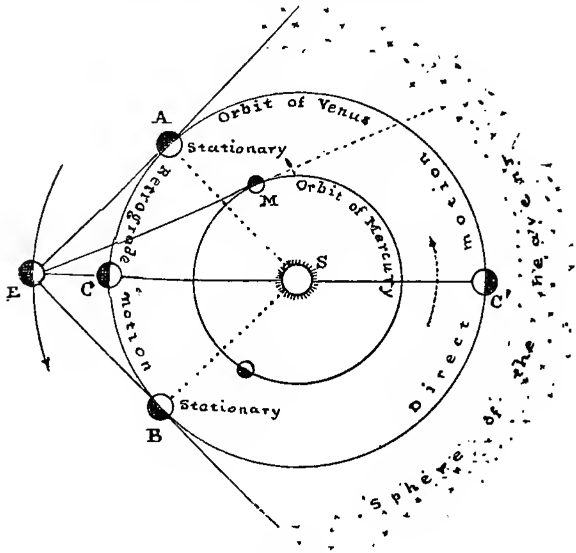


Fig. 75.

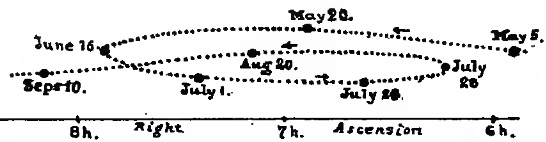
In the diagram we have the sun in the centre, and surrounding it the orbits of Mercury, Venus, and earth. Motion takes place in the direction indicated by the arrows, but for the sake of simplicity of explanation we may, for the present, suppose the earth to remain at rest.

When Venus is at A, or B, so that a line from the earth is tangent to the orbit of Venus, the planet appears to be coming directly towards the earth, as at A, or to be moving directly away from the earth, as at B. In both of these positions the planet is said to be *stationary*. Also, the planet is then said to be at its *greatest elongation*, east of the sun when at A and west of the sun when at B.

For the angle of greatest elongation we have $AS/ES = \sin AES$. Whence $AES = 46° \ 18'$. This angle is, of course, subject to small variations, but upon the average Venus never departs much more than 46° from the sun, and in its journey about the sun it appears, to us, to oscillate eastward and westward from side to side of the sun.

At C and C' Venus is in conjunction with the sun, C being inferior, and C' superior conjunction.

While the planet moves through the arc $BC'A$, it appears to move forwards among the stars, and is said to have *direct* motion, while in the remainder of its course it appears to move backwards among the stars, and is said to have *retrograde* motion. As the earth is all the while moving for-



Apparent path of Venus from May 5th to Sept. 10th 1900

Fig. 75a.

wards, the apparent path of Venus amongst the stars is very irregular as appears in the diagram. The planet appears to make a loop, more or less like the one represented, every 580 days.

Quite similar descriptions apply to the planet Mercury.

81. Evening and Morning Star.

When Venus is situated in the arc $C'AC$ it appears east of the sun in the heavens, and after sunset it appears in the

west as the evening star. If it be near the point *A* it will be quite high in the western sky at sunset, and will be brighter than any fixed star.

But when the planet is situated in the arc *CBC′*, it appears west of the sun, and rises in the morning before the sun, thus forming a morning star. It is then to be seen in the eastern horizon before sunrise.

Of course, any conspicuous starlike body which rises a short time before the sun or sets a short time after the sun, may appear as a morning and an evening star. But this name is usually applied only to the planets. Thus, Mercury is alternately morning and evening star, although it is rarely visible in high latitudes, on account of its departing only 25° from the sun, and on account of its small size. Jupiter and Saturn are also spoken of as morning and evening stars when in the proper positions, but Venus is the principal planet appearing in this rôle.

82. Phases of Venus.

In inferior conjunction Venus is only about 26 millions of miles from the earth, while in superior conjunction it is

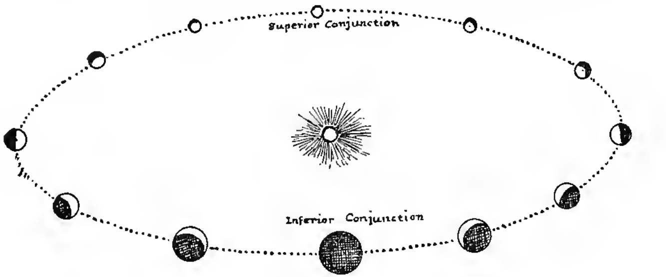


Fig. 76.

about 158 millions, so that its angular diameter varies from about 1′ when nearest the earth, to 10″ when farthest away. Also, the dark side of the planet faces the earth at inferior conjunction, and the planet would be invisible even if it

were not obscured by the powerful rays of the sun. As it leaves the inferior conjunction it gradually grows smaller in appearance, and passes through the various phases of the moon until the point of superior conjunction is reached, as illustrated in the accompanying figure.

83. Transit of Venus.

It is obvious that if an inferior conjunction of Venus takes place when the planet is sufficiently near one of the nodes of its orbit, the planet will be seen to cross the sun's disc as a small round black spot. This phenomenon, which we now propose to study, is called a transit of Venus.

Conditions of a Transit.

Let EAC be a section of the plane of the ecliptic, S be the sun, V the position of Venus when in inferior conjunction,

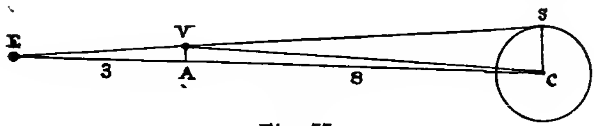


Fig. 77.

and E be the earth. Then by the application of continued fractions we obtain that $CA : CE = 8 : 11$ very nearly, so that if we take CA as 8, EA becomes 3.

Now, in the position V, the planet, as seen from the earth, just touches the limb of the sun and the angle $SEC = 16'$, nearly. But $\angle VCA = 3/8 \times VEC = 6'$. And this is the latitude of the planet when, as seen from the earth, it appears to graze the limb of the sun in passing the latter.

As the inclination of the orbit of Venus to the ecliptic is $3°\ 44'$, we readily find that the distance of the planet from the node, when its latitude is $6'$, is $6' \times \text{cosec}\ 3°\ 44'$, which works out to $1°\ 42'$. And if Venus is further from the node than this, its latitude is more than $6'$, and it will not transit the sun's disc in passing. But if it is nearer the node than

1° 42′, its latitude is less than 6′ and it will be seen to cross the sun in passing. And thus the whole transit limit is about 3° 24′ at each node, or 1° 42′ on each side of the node.

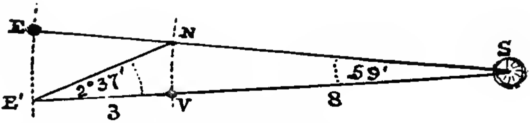


Fig. 78.

Let S be the sun, N a node of Venus' orbit, and E the earth in line with the node, the ecliptic being in the plane of the paper. The earth moves from E to E', through the angle $ESE'=59'$ in one day. And the angle by which it has passed the node is $NE'S$, which is $^8/_3$ of 59′, very nearly, or 2° 37′. So that the earth passes the node at the rate of 2° 37′ per day.

Again, 8 siderial years =2922.08 days.
and 13 revolutions of Venus=2921.10 days.

The difference is 0.98 days, during which time the earth will move over 57′ in regard to the sun, or over 2° 32′ with respect to the node.

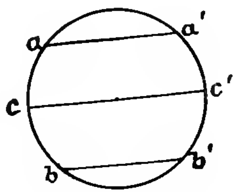


Fig. 79.

Hence, if at any time Venus is in inferior conjunction at the node, the conjunction 8 years afterwards will take place with Venus 2° 32′ past the same node.

From which it is readily seen that if a transit occurs as at aa', there may be a second transit 8 years after, as at bb', or vice versa, depending upon which node is concerned.

But if the transit be central as cc', or nearly so, there can be only a single transit, as the passages of Venus 8 years before and 8 years after, both fall beyond the transit limit.

After two transits, 8 years apart, there cannot be another transit for over a century. There were transits in 1874 and 1882, and the next two will be in 2004 and 2012.

Transits of Venus were looked upon, in the past, as astronomical phenomena of singular importance, as furnishing the means of finding the sun's horizontal parallax. Thus—Let

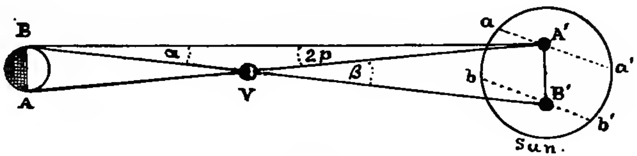


Fig. 80.

A, B be two observers upon the earth, and, for the sake of simplicity of explanation, let them be at the end-points of a diameter.

The observer at A sees Venus transiting the sun's disc along aa', and the observer at B sees it passing along bb'. Denote the angle $AA'B$ by $2p$, this angle being twice the sun's horizontal parallax. The angle α or $A'BB'$ is determined by the observation, which would be easily done if we could determine exactly the points A' and B', or the paths aa' and bb' on the sun's disc.

Let the angle $A'VB'$ be denoted by β. Then all the angles being very small, if E and V denote respectively the distances of the Earth and Venus from the sun,

$$A'B' = V\beta = E\alpha$$

$$\therefore\ \beta = \alpha E/V = \alpha + 2p, \qquad \therefore\ p = \tfrac{1}{2}(E/V - 1)\alpha.$$

Now *Kepler's law III* tells us that with any two planets, *the squares of their periodic times are proportional to the cubes of their mean distances from the sun*; or

$$(224)^2 : (365)^2 = V^3 : E^3.$$
$$\therefore\ E/V = (365/224)^{\frac{2}{3}} = 1.3847,$$
$$\text{whence, } p = 0.1623a.$$

So that when a is known p is readily found, and this is the sun's horizontal parallax.

Owing to the facts that transits of Venus occur so seldom and that it is difficult to get good reliable observations when they do occur, they are not considered of as much account as formerly. And of course they are out of account for the present century.

84. Mars.

As being our nearest superior neighbour of importance, Mars is of considerable interest to us. It is smaller than the earth, being only about 4210 miles in diameter, while that of the earth is 7920 miles. It possesses an atmosphere which is, however, much rarer than the terrestrial one. It revolves on its own axis once in $24^h\ 37^m\ 22^s$ of our time, and thus has its day and its night much the same in length as the earth has.

Its axis is inclined to the plane of its orbit at an angle of 25°, while that of the earth's axis is 23° 27′, and Mars has thus its seasons, spring, summer, autumn, and winter, much the same in order and relative character as we have.

It has its year of 687 of our days or about 669 of its own days. And it has its fields of ice and snow which gather around either pole during its long wintry night of darkness, and which gradually melt away, either in whole or in part, when the pole comes to bask in the continuous rays of the summer sun.

The orbits of earth and Mars are so situated relatively that the perihelion of Mars is only about 60° distant from the aphelion of earth, as is shown at *P* and *A*. The consequence is that at a point between these as at *E* and *M*, the two planets are separated by only about 36,000,000 miles, while if each were in the opposite points of their orbits they would be about 60,000,000 miles apart.

When the earth is between the sun and Mars, the latter is said to be in opposition, as at *M*; and when the sun is between the earth and Mars, as at *M'*, Mars is said to be in conjunction. When Mars is in opposition it comes to the meridian at midnight, and when in conjunction it is lost in the glare of the sun.

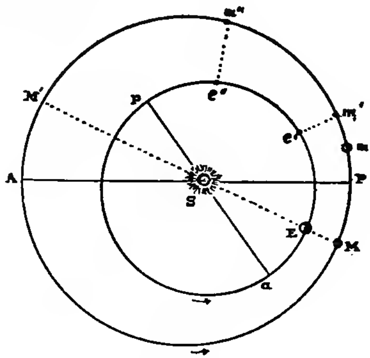


Fig. 81.

With the earth at *E* and Mars at *M'* their distance apart is from 225 to 250 millions of miles, so that the apparent angular diameter of Mars will be from 5 to 7 times as great when Mars is in opposition as it is when near conjunction. As a consequence, when near conjunction Mars appears as a very small star, while near opposition it almost rivals Venus at its best.

When Mars is at *m*, dwellers on the earth at *E* cannot see its whole enlightened face and it appears gibbous, or similar to the moon when about 10 days old. But the planet cannot, in any position, appear in a crescent form.

As the earth and Mars move in the same direction, as is indicated by the arrows, and the earth moves in angle considerably faster than Mars, in some part of the orbit, about the opposition, Mars will appear to move backwards amongst the stars. And thus, like Venus, Mars will appear to describe a loop in the heavens about the time of every opposi-

tion. The loop, however, is shorter than that described by Venus.

By working out the value of $(687\times365\frac{1}{4})/(687-365\frac{1}{4})$ we find the time elapsing between two consecutive oppositions of Mars to be 780 days, very closely, and this is about 50 days greater than two years.

So that if an opposition took place at *EM*, January 1st, 1900, say, the next opposition would be about 50° further on, at $e'm'$, on February 20th, 1902, the next at $e''m''$ on April 11th, 1904, and so on. And thus all the oppositions are not equally favorable for observations on the planet.

If, now, we form the convergents to the fraction 780/365, we find that a near convergent is $^{15}/_{7}$, and then $7\times780 = 5460$ days, while $15\times365\frac{1}{4}=5479$ days, nearly. So that after 15 years, or 7 oppositions, the oppositions return to within 19 days of their original place. And it can be readily shown that after 126 years the oppositions will return to within 2 days of their original places.

Mars, when in or about opposition, can be practically employed in determining the sun's horizontal parallax.

AB is the diameter of the earth, and for the sake of simplicity of explanation we will suppose observers to be placed at *A* and at *B*.

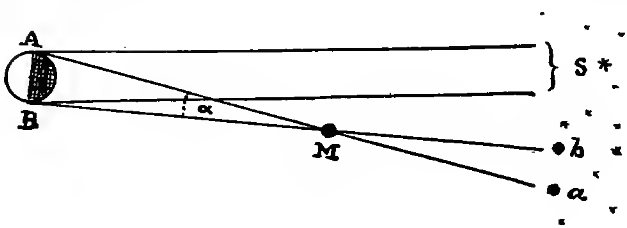


Fig. 82.

As seen from *A* and *B* the projections of Mars upon the surface of the heavens are *a* and *b* respectively. And if *S* be a star, *AS* and *BS* are parallel. The observers measure the angles *SAa* and *SBb*, and the difference of these is the angle *AMB*, which is denoted by α.

Then if e be the distance of the earth from the sun and m be the distance of Mars, $AM=m-e$; and if p be the sun's horizontal parallax,

$$AB=2pe=(m-e)\alpha\text{; and } p=\tfrac{1}{2}(m/e-1)\alpha.$$

And by Kepler's law III: $m/e=(687/365)^{3/2}=1.5246$,

whence, $p=0.2623\alpha$,

which gives the sun's horizontal parallax when α is known.

In carrying this out practically, the angle α is small, being only about 35″, and is difficult to measure accurately, and there are a number of small corrections to be made. But the method has the advantage over transits of Venus in that it can be repeated upon every favorable night for several weeks, at every opposition of Mars.

85. Moons of Mars.

Dean Swift, in his story of the Laputans (about 1700), described these people as having such good eyes and being such observant astronomers that they had discovered two moons to Mars, which they had called *Deimos* and *Phobos.*

And in 1877 Professor Hall actually discovered two moons attendant upon Mars and called them, respectively, Deimos and Phobos.

These moons are very small bodies, of some interest, no doubt, to the inhabitants of Mars, if such there be; but being invisible except through powerful telescopes, they are of little interest to dwellers upon the earth. Nevertheless, they offer the unique peculiarity that while the outer moon is an orderly body following the order of procedure of all other moons, the inner one has the time of its orbital revolution less than that of the axial rotation of Mars, so that it rises in the west and sets in the east.

86. Jupiter.

This is the giant planet of the solar system, being 86,000 miles in diameter. That is, about one-tenth of the sun's diameter. So that in bulk Jupiter is about 1300 times greater than the earth, and yet only one-thousandth part of that of the sun.

In spite of its great size, this planet rotates on its axis in something less than 10 hours. The result of this rapid rotation is plainly discernible in the elliptic form of its disc, which is manifestly due to the oblate-spheroidal form of the planet.

The greatest distance of Jupiter from the earth is to its least distance about as 3 is to 2, and as the brightness of the planet varies inversely as the square of the distance, the brightness at opposition is to that at conjunction as 9 is to 4. Thus, unlike Mars, Jupiter never becomes a very faint object, while, when at its best in favorable oppositions, it nearly rivals Venus in brilliancy.

As it travels about the sun in 433.2 days, it is easy to calculate that there will be an opposition every 398 days, or a little over 1 year and 1 month. So that if there be an opposition in any year early in January there will be an opposition the next year in February, the next year in March, and so on in every month except some month near the end of the list.

87. Jupiter's Satellites.

One of the first-fruits of the telescope in the hands of Galileo was the discovery of four moons revolving around Jupiter. In recent years several others have been discovered, but as these latter are visible only in the largest telescopes, while the four discovered by Galileo can be seen by an ordinary field glass, all the interest in the satellites of Jupiter centres about the four which were first seen, and which are, of course, much the largest.

The accompanying table gives the principal facts connected with these four small bodies:

Number.	Name.	Diam.	Distance from Jupiter.	Period of rev.
I.	Io	2350m.	267000m.	1.77 days.
II.	Europa	2090m.	425000m.	3.55 days.
III.	Ganymede	3430m.	678000m.	7.15 days.
IV.	Calisto	2920m.	1193000m.	16.69 days.

It will be noticed that the only one of these smaller than our moon is II, and that it is only 70 miles less in diameter; and yet, owing to the great distance of Jupiter from us, these moons appear as stars of the 6th and 7th magnitude, that is, scarcely visible to the sharpest normal eye.

Again, they are all farther from their central planet than our moon is from the earth, the most distant one being nearly five times as far. And yet the period of revolution of the most distant is not much more than one-half of that of our moon. This is due to the powerful attraction of the central planet; and we see that if Jupiter were to replace our earth, our moon would have to complete its revolution in about 40 hours in order to avoid being drawn into the centre of attraction. From considerations of this kind it is not difficult to compare the mass of any planet, which has a moon revolving about it, with the mass of the earth.

88. Eclipses, &c., of Jupiter's Satellites.

Knowing the sizes of the sun and of Jupiter, and the distance between them, a little calculation shows that the length of the umbra of Jupiter's shadow is about 54,000,000 miles, and therefore extends far beyond the orbit of the most distant moon.

As a consequence of this, and the fact that the inclinations of the orbits of the first three moons to the orbit of Jupiter are quite small, these moons pass through the shadow and are eclipsed at every revolution. But the inclination of the orbit of the fourth moon being greater, it is not eclipsed at every revolution but only at some of them. These eclipses are phenomena of some importance as observed from this earth.

But we have other interesting phenomena, besides eclipses, connected with the moons of Jupiter, namely, occultations of the moons as they pass behind the planet, and transits of both moon and shadow across the disc of the planet. The accompanying figure, which is necessarily much exaggerated in some of its dimensions, will help to explain the occurrence of these phenomena.

S is the sun, *GEF* the earth's orbit with the earth at present at *E*, *J* the planet Jupiter casting its dark shadow far out into space, and I and III the orbits of two of the moons, say the first and the third.

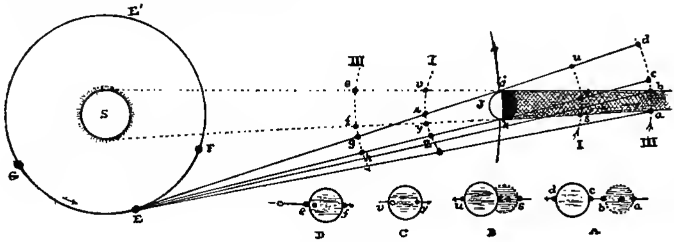


Fig. 83.

Considering moon III, when it reaches *a* it enters the shadow and is eclipsed, and at *b* it emerges from the shadow. At *c* it is seen to pass behind Jupiter and be occulted, or hidden, and at *d* it passes out of the occultation.

Thus from *a* to *b* there is an eclipse and from *c* to *d* an occultation, and these are both visible from the earth at *E*.

At *e*, on the other side of its orbit, moon III casts its shadow on the disc of the planet; and as the moon moves from *e* to *f* the shadow, in the form of a dark spot, is seen to traverse the face of Jupiter. At *g* the shadow has passed off from the disc and the moon itself, as a light spot, is seen to enter and to pass across the disc of the planet as the moon moves from *g* to *h*. So on one side we witness an eclipse and then an occultation, and on the other side a transit, first of the shadow, and then of the moon, all being visible at *E*. If the earth were at *E′*, the phenomena would be the same but in a reversed order. These appearances are represented by *A* and *D*, where the shaded circle represents a section of the planet's shadow where the moon III traverses it.

In the case of moon I, or even III, the satellite is so near the planet that the eclipse passes into the occultation without the moon becoming visible between, as represented at *B*, and the transits of the shadow and of the moon may both be seen upon the disc at the same time, as at *C*.

If Jupiter were inhabited, every point traversed by the shadow in its passage across the disc would witness an eclipse of the sun. And astronomers on such a planet would be kept busy predicting eclipses, if indeed their very commonness did not destroy the interest in them.

Eclipses and shadow transits are independent of the earth's position in its orbit, and would be the same as seen from any other planet; that is, as phenomena, they are absolute, and their beginning and end mark absolute moments of time; but such is not the case with the occultations and the moon transits.

89. Determination of Longitudes by Eclipses of Jupiter's Moons.

Given two places A and B, the difference in their mean time clocks is their difference in longitude. But if A and B could observe and record, in mean time, the occurrence of an absolute event, they would have the difference in their mean time clocks. And the eclipses of Jupiter's satellites are such events. These are predicted to take place at certain times at Greenwich, and if they are observed at B, then B can compare its time with that of Greenwich and thus determine its longitude.

This means of finding longitudes is quite correct in theory, but in practice it is found to be very difficult to say just when an eclipse begins or ends, as the obscuration of the moon is not an instantaneous event but a gradual one. And on this account results obtained by this method are only close approximations, which can be made closer, however, by multiplying the number of observations.

90. Progressive Motion of Light.

Soon after the discovery of Jupiter's moons, tables were constructed showing the times of eclipses for the purpose of observing them. These were made for a mean position of the earth, as at E, and it was soon noticed that when the earth came into a position such as F, with Jupiter near opposition, the eclipses invariably happened about 7 or 8 minutes before their calculated times; and that with the earth at G, and Jupiter near conjunction, the eclipse happened 7 or 8 minutes too late.

Roemer, a celebrated Danish astronomer, in speculating upon these facts, came to the conclusion that light is not propagated instantaneously but progressively, that is, that light requires time to pass from one point in space to another. And he computed that it would require nearly 17 minutes for light to cross the orbit of the earth, or, more exactly, $8\frac{1}{3}$ minutes to come from the sun to the earth. So that if the sun could be instantaneously blotted out we would continue to receive its light and heat for $8\frac{1}{3}$ minutes after.

Thus the velocity of light became a problem in astronomy.

Several classical and successful experiments have been carried out for determining the velocity of light, but we shall here consider only one of them, namely, Foucault's experiment.

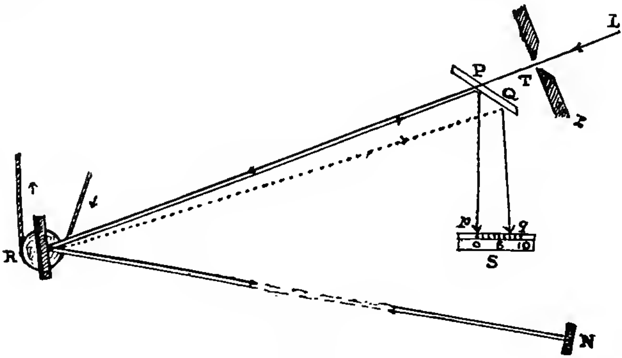


Fig. 84.

A ray of light from the sun, or any other source, passes through a narrow slit, T, in a shutter or other contrivance, and falls upon the mirror, R, which is so attached to a pulley as to be revolved at any required speed. N is a mirror at any distance from 2 miles to 5 miles from R and so adjusted that light coming to it from R will be reflected directly back to R, and thence along the direction RT.

At P a plane unsilvered glass is placed so that it may intercept a portion of the rays coming back from R, and reflect them to p on the scale S.

Things being thus arranged, the mirror R is made to revolve. Then a ray of light takes some time, however small, to go from R to N and back again; and during this time the mirror R has turned somewhat, and instead of sending the ray back to P it sends it to Q, whence it is reflected to q.

And thus if Pp, with R at rest, be brought to zero mark on the micrometer at the eye-end of a telescope, and R then be put in motion, Pp is displaced in the direction of Qq, and the amount of displacement is proportional to the velocity of R.

Hence, knowing the distance RN, the rate of revolution of R, and measuring the displacement of Pp, it is not difficult to calculate the velocity of light.

Of course, there are always discrepancies in the results of very delicate experiments, but the mean of a great number of trials may be taken as 186,000 miles per second.

If, then, it takes $8\frac{1}{3}$ minutes for light to come from the sun to the earth, the sun's distance must be 93,000,000 miles. The time $8^m\ 20^s$ is called *the equation of light.*

91. Aberration of the Stars.

For an explanation of this subject, the following illustration will probably be sufficient:

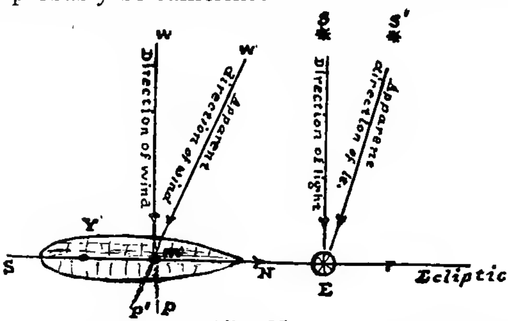


Fig. 85.

Y is a yacht at rest, headed to the north, say; *m* is the masthead, and *mp* is the pennant pointing eastward from a west wind *wm.*

As long as the yacht remains still and the wind is west the pennant will be directed eastwards. But as the yacht gets in motion northwards the pennant will gradually shift to a direction mp' as if the wind were coming from w', and a person ignorant of the cause would say that the wind had shifted somewhat towards the north. The fact, however, is that the apparent direction of the wind is the resultant of the eastern direction of the wind and the northern movement of the yacht.

Now let the yacht represent the earth, E, moving along the ecliptic, the wind represent the light coming from a star, S, at the pole of the ecliptic, and the pennant represent a telescope so directed as to point to the star.

If the earth were at rest, the direction of the telescope would be ES, perpendicular to the plane of the ecliptic. But as the earth is in motion, the telescope must necessarily be deflected to the direction ES', and the star appears to be at S'. The angle of displacement SES' is the star's *aberration*, and it is readily seen that its radian measure is *the ratio of the velocity of the earth to the velocity of light.*

Aberration throws a star forwards in the direction parallel to that of the earth's motion, so that the star S' will apparently describe a small curve similar to the earth's orbit, or practically a circle, about the true place S. There is no aberration of a star when the earth is moving directly towards it or away from it, and the aberration is a maximum when the direction of the star is normal to the earth's direction of motion. Thus, stars in the plane of the ecliptic oscillate backwards and forwards in a line once a year, and stars between the plane of the ecliptic and the pole of the ecliptic apparently describe ellipses, of which the major axes are constant and parallel to the ecliptic, and the minor axes vary from zero for stars in the ecliptic to equality with the major axis for the star at the pole of the ecliptic.

The discovery of aberration was purely a matter of observation and was made by Bradley in 1725, on the star γ Draconis, when looking for something entirely different. And repeated observations have established that the average value

of the aberration, or of the angular value of the major axis of the ellipse, is $20''.49$. This is called the *constant of aberration.*

92. Finding Sun's distance from constant of aberration.

This is one of the reliable methods of finding the sun's distance, and the necessary calculation is not difficult.

Let R be the mean radius of the earth's orbit in miles; S be the number of seconds in a year; and λ be the velocity of light in miles per second.

Then $2\pi R/S$ is the orbital velocity of the earth in miles per second; and

$2\pi R/S\lambda$ is the radian value of the constant of aberration, that is of $20''.49$.

But $S=365.25\times24\times3600$; and $20''.49$ expressed in radians is $20.49\times\pi/180\times3600$.

Whence

$$R=92{,}800{,}000 \text{ miles, nearly.}$$

This is probably the most satisfactory method of finding the sun's distance. Of course, its accuracy depends upon that of our knowledge of the velocity of light, and the closeness with which the constant of aberration can be obtained. The uncertain element is the velocity of light. For experiments give us the velocity of light when passing through the atmosphere, and this undoubtedly differs slightly from its velocity when passing through the space which intervenes between the earth and the sun. The difference, however, must be exceedingly small.

93. Saturn.

This planet is interesting through its uniqueness. It is a large planet, having a diameter of over 73,000 miles, and is next to Jupiter in size. Its distance from the sun is upwards of 900 million miles, or nearly 10 times the distance of the earth. It revolves on its axis in the short time of $10\frac{1}{2}$ hours, and it requires $29\frac{1}{2}$ years to complete its journey about the sun.

Saturn is supplied with 9 moons, at least, and probably more, so that it forms in itself a very good type of the whole solar system. But the most distinguishing feature of the planet, and the one which brings it into prominence as a celestial object is the peculiar and unique system of rings which surround the planet.

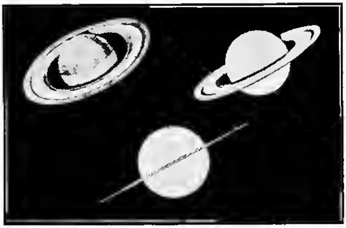


Fig. 86.

The rings consist principally of three parts or divisions, an outer bright ring, an inner bright ring, and a still more inner ring, generally known as the crepe or fluid ring.

The bright rings, and probably the crepe one also, are very flat and thin. For, while the whole diameter of the largest ring is about 165,000 miles, the thickness is probably not above 200 or 250 miles, and may be less.

The plane of the rings is coincident with the plane of the planet's equator, and this is inclined at the average angle of about 25° to the ecliptic, so that as the planet passes around in its orbit, the rings present different phases to the earth. In this way we are enabled to see sometimes one face of the rings and at other times the opposite face. During these changes the rings come, about every 15 years, into such a position that their plane passes through the earth, and we see the rings " edge on." In this position they become barely visible as a slender continuous or broken line crossing the planet. We have here a practical proof that the rings must be very thin as compared with their other dimensions, the thickness not rising to probably above 200 or 250 miles.

In the figure are three views of Saturn. The two upper views show the rings more or less opened out, and the lower one the appearance when the plane of the ring passes through the earth and the ring is seen "edge on."

Naturally, these rings have been great subjects for the speculative astronomer and physicist. And how they managed to maintain their positions and not fall in upon the body of the planet, or upon one another, if they were solid, as they appear to be, was a standing puzzle. But the puzzle has been solved by dropping the hypothesis of a solid ring, or of a ring in which the constituent parts are held together by any forces except the universal attraction of gravitation.

The only tenable hypothesis and the one now generally held is that the rings consist of immense swarms of meteoric bodies, each revolving about the central planet upon its own account like a tiny moon, and, of course, each being subject to disturbances arising from the attractions of the others.

That the bodies may not be very near together is shown by the fact that a stretch of 50 or 60 miles would be scarcely distinguishable at the distance of Saturn, and that two bright bodies that far apart would merge their light into one. And when we consider that we are looking through great depths of such bodies, it is readily seen that the individual meteoroids may be a number of miles apart and yet appear as a luminous whole.

There must, in such a system, be a great amount of interference and numerous collisions, the general consequence of which would be that great numbers of the bodies would be deflected from their courses and be caused after a time to fall upon the planet. This is possibly the meaning of the faint crepe ring; and it is altogether probable that the surface of Saturn is being continuously bombarded by meteorites to an extent surpassing all human experience, and that at some time in the distant future the rings may be completely precipitated upon the central body.

It is said that Sir Wm. Herschell, the foremost astronomical observer of his time (1738-1822), makes no mention of the crepe ring in any of his writings; and it is inferred that

it was not then a conspicuous object. If the inference be correct, we must conclude that this ring is rapidly growing, and that the rings of Saturn are probably comparatively recent introductions into the solar system.

94. Uranus and Neptune.

These are both large planets, but from their great distance they are both telescopic and therefore of much less interest than the other planets.

Uranus is supplied with four moons, as far as is known, and Neptune with one. Neptune is about 30 times as far from the sun as the earth is, and nothing can be said to be known about its individual character.

SURFACE CONDITIONS OF THE PLANETS.

One planet at least, the earth, is the home and abode of life and organic beings, and we are accustomed to associate with the presence of life the presence of certain conditions prevailing upon the surface of this earth, and which are thought to be necessary to the existence of life.

It is not at all certain that our estimate of the necessary conditions is a correct one, and some recent discoveries in this line have shown that former estimates would need some material modification.

Nor is it certain that we can attain to anything like exact knowledge as to the surface conditions of any planet except our own. But we may, by careful reasoning from what we know, arrive at certain results that are highly probable, and we may rest quite surely in the assumption that wherever the surface conditions of a planet are favorable to the development of life, there life is present, whether we can obtain any direct evidence of its presence or not.

95. General Conditions for an Atmosphere.

We have, in this earth, a planet surrounded by a well defined atmosphere, and we shall try to determine some of the

conditions necessary for the existence of a planetary atmosphere.

According to physical theory a gas consists of exceedingly minute particles or molecules which are far apart as compared with their size, and which are moving in straight lines with very high velocities.

Thus, the average velocity for oxygen is believed to be about 15 miles a minute, while the molecule of hydrogen moves about four times as fast or practically a mile a second. These flying molecules must frequently come into collision, and as they are perfectly elastic, some of them will have their velocity temporarily increased while others will have it diminished; and Clerk-Maxwell concluded that in this way the highest obtainable velocity for any molecule might be 6 or 7 times the average velocity.

The accompanying table gives this highest velocity for the gases of our own atmosphere at the temperature of zero Centigrade:

Hydrogen	7.4	miles	per	second.
Water Vapor	2.5	"	"	"
Nitrogen	2.0	"	"	"
Oxygen	1.8	"	"	"
Carbon dioxide	1.6	"	"	"

Now, the temperature of a gas is but another idea for the average velocity of its particles, so that when the temperature is reduced the average, velocity and therefore the maximum, must be reduced also. And as it is not possible, at present, to say what the temperature of the air may be at a height of 60 or 70 miles, we see that in the applications of this principle to be made hereafter we must allow ourselves considerable latitude.

Again, if on any planet a particle be projected outwards with sufficient velocity, the particle would, by its momentum, overcome the planet's attraction and pass away into space. The minimum velocity sufficient for this is called the *critical velocity* for the planet.

The critical velocities for the sun and all the principal planets are easily found, and are given in the following table, the only doubtful one being Mercury:

Moon	1.5 miles per sec.	Jupiter	37 miles per sec.
Mercury	2.2 miles per sec.	Saturn	22 miles per sec.
Venus	6.6 miles per sec.	Uranus	13 miles per sec.
Earth	6.9 miles per sec.	Neptune	14 miles per sec.
Mars	3.1 miles per sec.	Sun	382 miles per sec.

By a comparison of the two preceding tables it would appear that hydrogen can be retained only by the sun and the four outer planets. In the atmosphere of these planets, then, hydrogen in a free state might be present, although this is not probably the actual case. For there can be no doubt that oxygen would be present in large quantities, and unless the amount of hydrogen exceeded that of the oxygen, all the hydrogen would in a short time unite with the oxygen present to form water vapor. But if we may judge from analogy with the earth, oxygen is present in much larger quantities than hydrogen.

Again, the moon is not capable of retaining any of the previous list of gases upon its surface, and it must be therefore devoid of any atmosphere, provided this principle is rigorously applied. It is well known that observations on the moon have so far shown no trace of the existence of an atmosphere.

Mercury, being a very small planet, would find difficulty in retaining any atmosphere except a very rare one, and that would probably contain a larger percentage of carbon dioxide than is the case with the terrestrial atmosphere.

The atmosphere of Venus should be very similar to that of the earth in both composition and density, while that of Mars should be much the same in composition, but of much less density, owing to the smaller size of the planet.

Again, the spectroscope shows that, with two exceptions, coronium and nebulum which are found only under peculiar unique circumstances, all the chemical elements discovered in the sun and stars are common to this earth. So that we

are justified in believing that all the bodies of the universe have practically the same chemical constitution and contain the same chemical elements, whether they have the same physical constitution or not. In other words, terrestrial chemistry is practically the chemistry of the universe, just as terrestrial physics is a part of its common physics. Hence, when two planets have atmospheres we must infer that these atmospheres are closely akin to one another, if not identical, in chemical composition, as also to a very great extent in their physical qualities.

So that to hold that one planet may have a considerable atmosphere mainly composed of carbon dioxide while in the atmosphere of another planet this gas is present in only a small percentage of the whole, is illogical.

Again, the surface condition of a planet will depend upon the amount of heat which the planet receives from the sun, or at least upon the proportion of this heat which it retains. Thus, other things being the same, a planet with a dense atmosphere rich in water vapor will be warmer than a planet with a thin atmosphere.

But a planet having a high internal temperature, as is the case with the four large outer ones, might, by slow conduction of heat from within outwards, remain for long ages quite independent of the heat of the sun.

In endeavoring to arrive at some knowledge of the surface conditions of the several planets, the most rational way seems to be to begin with the earth, the planet that we know best, and then compare the conditions which probably exist on the other planets with those known to be present on the earth.

96. The Earth.

The earth's atmosphere consists principally of a mechanical mixture of the two gases, nitrogen and oxygen, in the proportions by weight of about 78 nitrogen to 22 oxygen. These two gases, which undergo no change at any temperature found upon the earth, liquifying only when near absolute zero, form the great bulk of the atmosphere, and are

present in every locality in almost exactly the same proportions. And these two gases would naturally be present as the chief constituents of the atmosphere of every planet which possesses an atmosphere of any density.

Carbon dioxide and water vapor, although present in small and varying quantities, are yet essentials and play an important part in the economy of nature. The average amount of carbon dioxide present is about 6 parts in 10,000 of air, and the water vapor may vary from almost zero in the midst of an extended dry and arid plain, to nearly 2 per cent. in a warm and moist climate.

The nitrogen of the air may play some important part, but its principal apparent function is as a diluent of the oxygen in order to prevent too vigorous action of the latter element.

The oxygen is essential to combustion and therefore to respiration and animal life, while the carbon dioxide, which is produced amongst other ways by the breathing of animals, is necessary to the life of plants, being, in fact, their principal food.

And water vapor in the atmosphere is not only necessary to both plant and animal life, but serves other numerous and important purposes in the functions of the atmosphere in its relation to climate.

97. Terrestrial Atmosphere.

Air is a mixture of elastic gases so that the lowest layer is compressed by the weight of all that lies above it, and as a consequence the tension is greatest at sea-level and decreases quite rapidly as we ascend. At some point of elevation the attraction of gravitation on the particles must be equal to the repulsive force between the particles. This must form a sort of upper limit to the atmosphere, although this limit is somewhat illy defined and undoubtedly undergoing constant changes in elevation, as it is acted upon by the attractions of both the sun and the moon.

The whole height of the atmosphere is believed to be somewhere about 100 miles.

The average weight or tension of the atmosphere at sea-level is about 15 pounds per square inch, or equal to that of a column of mercury 30 in. high. As we go upwards this tension diminishes at a rapid rate, so that at about ~~7~~ miles high the tension is only 7½ pounds per square inch, and you have left one-half of the atmosphere below you.

By measuring the weight or tension of the air at any given point of elevation it is possible to calculate the height of that point above sea-level. In this way the height of stations on the side of a mountain may be determined.

Sound. Air is the vehicle of sound, so that the surface of a planet without an atmosphere would be noiseless and as quiet as death.

Temperature. The whole air to some extent, and the vapor of water especially, exercises a marked influence over temperature. Upon the top of a mountain where there is a minimum of water vapor the sun shines brilliantly and its direct rays become inconveniently warm, while the shade is disagreeably cool, and a chill settles over the place as the night comes on. But in the valley near the sea-level, with an atmosphere nearly saturated with water vapor, the whole air gets warm and there is very little difference in temperature between the sunshine and the shade.

Water vapor, and hence cloud, acts as a sort of a trap which allows the intense rays of the sun to pass inwards without difficulty, but which resists the passage of the less intense heat rays outwards. Thus the water vapor in the general atmosphere acts much the same part as the glass in the roof of the gardener's hot-house.

A planet with a dense atmosphere filled with water vapor would have its day and night temperature more or less equalized, while a world without an atmosphere would be subject to great extremes of temperature between day and night.

We have illustrations of these things in the facts that, other things beings equal, a cloudy night is warmer than a clear one, and a warm day with a damp "muggy" atmosphere is more disagreeable than if the atmosphere were dry.

The temperature of the atmosphere decreases as one goes upwards, although not at a uniform rate, and the law of decrease appears to be a somewhat irregular one. The temperature at a height of 15 or 20 miles is not known with any certainty, but it is probably pretty low.

Wind. This is but air in motion. We could scarcely imagine a great mass of gas, surrounding a rotating planet, to be at rest. As the relation of the sun's rays to the surface of the earth is continually changing from hour to hour of the day, and from day to day of the year, the surface conditions of temperature can never be the same for any length of time throughout any extensive region. In a warm locality the air expands and rises and other air from cooler surroundings comes in to fill the void. If a large body of water is near there will be a sea breeze.

The general character of the wind will depend upon the density of the atmosphere, and the difference of temperature between adjoining regions. When this difference becomes very great the wind may rise to a storm or a cyclone, although the most of the destructive storms are probably due to special conditions.

Regular winds, as the trades, are partly determined by the earth's axial rotation, and so also are the prevailing northwest wind in the north temperate zone and the prevailing southwest wind in the south temperate zone.

Where the atmosphere is of sufficient density to support them, clouds will be formed, and hence there will be rain or snow and hail according to circumstances of temperature.

Light and Color. To a person in a darkened room, a pencil of sun-light coming through a small hole makes its path distinctly visible by illuminating the dust particles and even, to some extent, the molecules of atmosphere in its course. So also the beam from a search-light on a dark and cloudy night makes its presence known by the illuminated track which it pencils out far up into the sky.

Thus the general brightness of the day and the blue color of the sky are due to the presence of the atmosphere. Without an atmosphere the sky would probably appear black, or

nearly so, and the stars would be brilliant even in the day time. Everything receiving the direct rays of the sun would be strongly lighted, but shadows would be generally dark, and rapidly shading into blackness. There would be no twilight; but night would follow day so suddenly as to be bewildering, although the greater brilliancy of the stars at night would render the darkness less dense than if an atmosphere were present.

Refraction. It is a fundamental principle in optics that when a ray of light passes obliquely from one medium into another of different density, the ray suffers a bending or refraction at the common surface of the media.

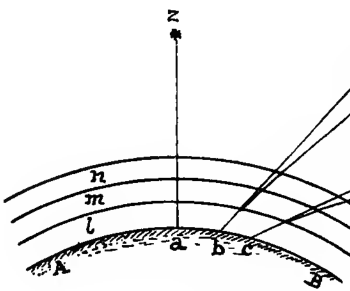


Fig. 87.

Now the atmosphere grows denser from above downwards, and for the purpose of illustration we may suppose it to be divided into layers *l, m, n,* etc., where *l* is more dense than *m*, *m* more dense than *n*, etc. Then rays of light from the star *s* are bent downwards as they pass from space into layer *n*, again as they pass from *n* into *m*, and from *m* into *l*. So that the light meets the eye of the observer, at *c*, as if it came directly from *s'*.

As the layers of atmosphere are made thinner, and correspondingly increased in number, the path of the ray through the atmosphere assumes the form of a curve, and the apparent place of the star is above its true place.

Thus the effect of refraction upon the heavenly bodies is to increase their apparent altitudes, the increment being greatest at the horizon, and vanishing at the zenith.

In getting the true altitude from an observation the refraction is always subtractive, that is, it has to be subtracted from the apparent altitude.

The amount of the refraction depends upon the temperature and also upon the height of the barometer, or the weight of the atmosphere at the time of observation, and these must be considered where accuracy is required.

The following table gives the refraction to the nearest tenth of a minute, for every degree of altitude from 1° to 90°, for a mean value of the thermometer and barometer:

TABLE OF REFRACTION.

Alt.	Ref.	Alt.	Ref.	Alt.	Ref.	Alt.	Ref.	Alt.	Ref.	Alt.	Ref.
°	′	°	′	°	′	°	′	°	′	°	′
1	24.4	16	3.4	31	1.6	46	0.9	61	0.5	76	0.2
2	18.4	17	3.2	32	1.6	47	0.9	62	0.5	77	0.2
3	14.5	18	3.0	33	1.5	48	0.9	63	0.5	78	0.2
4	11.8	19	2.8	34	1.4	49	0.8	64	0.5	79	0.2
5	9.9	20	2.6	35	1.4	50	0.8	65	0.5	80	0.2
6	8.5	21	2.5	36	1.3	51	0.8	66	0.4	81	0.2
7	7.4	22	2.4	37	1.3	52	0.8	67	0.4	82	0.1
8	6.6	23	2.3	38	1.2	53	0.7	68	0.4	83	0.1
9	5.9	24	2.2	39	1.2	54	0.7	69	0.4	84	0.1
10	5.3	25	2.1	40	1.2	55	0.7	70	0.4	85	0.1
11	4.9	26	2.0	41	1.1	56	0.7	71	0.3	86	0.1
12	4.5	27	1.9	42	1.1	57	0.6	72	0.3	87	0.1
13	4.1	28	1.8	43	1.0	58	0.6	73	0.3	88	0.0
14	3.8	29	1.7	44	1.0	59	0.6	74	0.3	89	0.0
15	3.6	30	1.7	45	1.0	60	0.6	75	0.3	90	0.0

It will be noticed from the table how large the refraction is for an altitude of 1 degree, and how rapidly it falls for the first 5 or 6 degrees. Now, there is always some uncertainty about the refraction when it is very large, so that it is not well, if it can be avoided, to depend too much upon observations made on the altitudes of heavenly bodies near

the horizon. And in order to find latitude accurately it is profitable to observe stars as near the zenith as possible, and thus get rid of the uncertainty of refraction.

When light from the sun traverses great stretches of atmosphere, and especially when water vapor is present in considerable quantity, the light loses some of its constituents by absorption. But these constituents are not taken out in equable proportions. The rays about the violet end of the spectrum are removed in larger proportion than those in the vicinity of the red end, and as a consequence the transmitted light assumes a ruddy hue from having the red constituent in excess.

This is the reason why the sun appears red when seen through a mist or fog, and why it is more or less golden in color at its rising and its setting.

Thus the beautiful tints of the evening clouds with their rich sheen of red and gold, the rosy blush of the dawn, and the general color effects so beautiful at times in the higher atmosphere, are all due to the same cause, the presence of air containing vapor of water. The visibility and color of the moon when immersed in the depths of the earth's shadow are due to a like cause.

Meteors and Falling Stars. Meteors, such as come under our observation, are originally small pieces of mineral matter scattered through space, and, of course, moving in some kind of an orbit about the sun as a centre of attraction. They exist in immense numbers and vary in size from that of a mere dust particle to stony bodies of some considerable bulk. Some of these naturally come very close to the earth and many fall upon its surface.

If it were not for the atmosphere none of these which now are precipitated upon the earth would be visible. But meeting the atmosphere at a velocity of from 15 to 30 miles a second, the heat generated is so great as to raise the moving particle to incandescence and dissipate it into impalpable dust, which after floating in the air for a longer or shorter time finds its way to the earth. It is while incandescent and

being gasified that the particle leaves a trail of light in its path and resembles a falling star.

If the meteorite be of considerable size, it may not be wholly dissipated, but may fall to the earth as a solid stony or metallic mass, of which the surface only has been fused, and bury itself deep in the soil. And from such a position they have occassionally been resurrected while still quite hot.

Sometimes, again, the heat generates gases in the interior of the meteorite, and the resulting pressure bursts the mass with a loud report and scatters the fragments in various directions, with an appearance very much like the explosion of a rocket.

It has been estimated that about six million meteorites, of all kinds, fall to the earth every 24 hours. As they are probably at less than 100 miles from the earth's surface when first becoming visible, it is evident that only a very small proportion of the whole is visible at any one locality.

November and August Meteors. There are two well-recognized rings of meteoric matter surrounding the sun, and circulating about it in their own plane, each meteorite, of course, moving under the law of gravitation as a minute independent planet. These rings are so situated that the earth, in its annual revolution about the sun, comes into contact with a ring and passes through it, the one on November 14th and the other on August 12th or thereabouts. As a consequence, the earth is treated to a distinct shower of meteors on or about these two dates.

Of course, the phenomenon, in both cases, is local and can be seen only from that side of the earth which is advancing upon the meteoric ring, and then only if it be night at the locality. The phenomena show themselves as a distinct increase in the number of " falling stars " to be seen.

Zodiacal light. This subject, although having no direct connection with the atmosphere, is intimately related to that of meteorites.

Besides the two rings of meteoric matter, through whose substance the earth has to pass in November and August, there may be, and probably are, numerous other rings, more

or less diffused, which, from lying wholly outside the earth's orbit, or wholly inside, are never met by the earth in its course, and consequently never reveal their existence by a display in the upper atmosphere. And it is generally held by astronomers that the sun is surrounded by an extensive expanse of meteoric matter of very low density and extending outwards as far as the earth's orbit or even beyond it.

This would account for the innumerable host of small meteorites which are met by the earth throughout its annual course, as well as for that peculiar phenomenon known as the *zodiacal light*.

The zodiacal light appears as a faint triangular-shaped halo of light rising from the western horizon after sunset. It is most conspicuous in torrid climes; and in northern regions it is seen best in the spring as the ecliptic, along which it lies, then cuts the horizon at the greatest angle.

Imagine the sun to be surrounded by a very diffuse lenticular expansion of meteoric matter with the plane of the lens nearly coincident with that of the ecliptic, and extending outwards to the distance of the earth's orbit, or nearly so. Such an expansion, by reflecting the light of the sun from its innumerable particles, would give quite accurately the appearance of the zodiacal light.

There are strong reasons for believing that this is the cause of the phenomenon. And it is probable that this meteoric matter, as also the meteoric rings already referred to, are merely refuse matter from the evolution of the solar system, and from the disintegration of innumerable comets which have wholly or partly lost their integrity by too close proximity to the sun.

98. The Moon.

Theoretically the moon can have no atmosphere, as it cannot retain any of the atmospheric gases upon its surface. Hence, life cannot be present and the silence of death must envelop it.

Its surface must be wholly rock or volcanic products, where disintegration and the formation of soil are impossible

processes, as these are due to the "weathering" effects of an atmosphere.

The face turned for 14 days to the light and heat of the sun probably rises to a very high temperature, while that immersed for a like time in the gloom of night sinks towards the temperature of space, whatever that may be. But even that does not necessarily mean that the temperature should approach absolute zero, for the north pole of the earth remains cut off from the rays of the sun for five months at a time and yet, as far as is known, the thermometer scarcely ever reaches 100° below zero Fahrenheit even under these conditions.

The shadows should be very dark and the sky quite black, while the stars should shine out with a brilliancy unknown upon earth.

If an atmosphere were present on the moon, a star, when being occulted or hidden behind the moon, should be somewhat displaced by refraction and should lose its light gradually. This, however, is not the case. The star comes to the edge of the lunar disc without any displacement, and then suddenly vanishes; plainly showing that the moon has no atmosphere.

Moreover, as long and as often as the moon has been observed and mapped and photographed, not a single well indicated change has appeared upon its surface.

The lunar disc is quite covered with ring mountains with or without a central cone, and small cup-shaped cavities with elevated edges are plentiful everywhere. These show the great extent of volcanic action in past ages.

A few years ago some astronomers thought that present volcanic action was to be seen in the crater Linné, but later observations have not corroborated this, and it is now generally held that the surface of the moon is practically dead in every sense.

The sharp and jagged peaks of the mountains cast their black shadows into the valley of the crater or across the adjacent plain, and lengthen out wonderfully as they are approached by the terminator. By measuring the lengths of

these shadows it is possible to calculate the heights of the peaks above the surrounding regions. In this way Beer and Mädler estimated that some of the mountains are not less than 20,000 feet high.

The moon does not appear uniformly bright, but is more or less mottled with darker spots. These, which were formerly supposed to be seas, are seen in the telescope to have small craters scattered through them, thus showing that they are not now seas, whatever they may once have been. The disposition of these darker parts gives rise to the fanciful figure of the "man in the moon" and other like things.

The accompanying plates will serve to give some general idea of the character of the lunar surface.

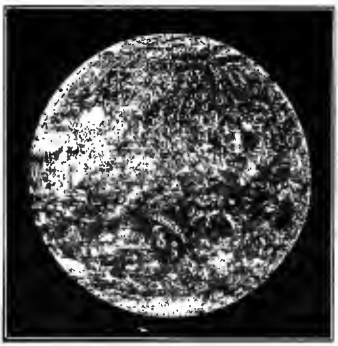


Fig. 88.

Fig. 89.

Fig. 88 is a selenographic map of the moon, showing the general positions of the mountains on its surface. The most mountainous region is around the moon's south pole, which here appears at the top of the figure, on account of the inversion produced by the astronomical telescope.

Fig. 89 shows the moon a little past the first quarter, and the irregularity of the terminator gives a very good idea of the character of the surface. The conspicuous ring mountain just on the terminator is *Copernicus*.

Fig. 90 is an enlarged view of Copernicus, showing the roughness of the ring and generally of the surrounding region. The great number of small craters, adjacent to the main one, is well brought out.

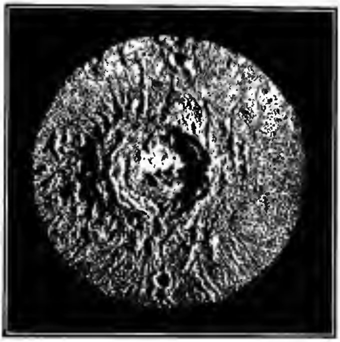


Fig. 90.

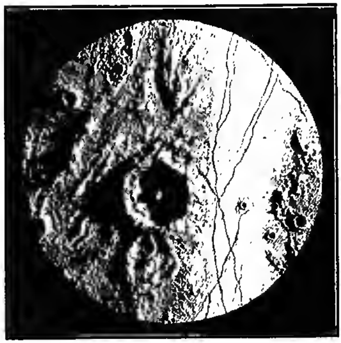


Fig. 91.

Fig. 92.

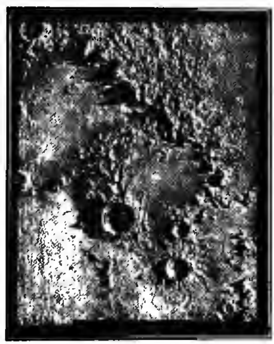


Fig. 93.

Fig. 91 is the ring mountain *Triesnecker*, with top of the central cone lighted by the sun, and the height of the ringed wall may be judged of by the extent of the shadows. The adjacent smoother part of the surface is traversed by several very prominent cracks.

Fig. 92 shows the mountains *Theophilus, Cyrillus,* and *Catharina.* The whole structure is peculiar, showing how one ring sometimes invades the possessions of another.

Fig. 93 shows a range of mountains, towards the moon's rthern ~~southern~~ limb, which do not appear to be volcanic, but more after the character of the Alps. These are the lunar *Apenines*, and the ruggedness of their character is shown by the long pointed shadows cast by their peaks.

Various superstitions and fanciful notions have been connected with the moon, in times past, such as its influence over people and over the weather, and in regard to its power as an oracle or a charm. The most of these are gradually disappearing with the diffusion of correct astronomical information, but many of them die hard.

The moon is many times larger than the largest known asteroid, so that it would be idle to expect the presence of life or even an atmosphere upon any of the asteroids.

99. Venus.

In a transit of Venus, the outline of the dark body of the planet is plainly seen for some time before the planet has fully advanced upon the solar disc, thus showing that Venus is surrounded with a well-defined atmosphere; and some astronomers have held that the atmosphere of Venus is even more dense than the terrestrial one. And from previous considerations we infer that the two atmospheres, that of Venus and that of the Earth, are much alike in their general composition and character.

But as Venus exposes continually the same hemisphere to the sun, the surface conditions must be somewhat different from what they are with us.

The temperature of the bright side must be very high, especially about the central parts, unless very dense clouds prevail, and the temperature of the dark regions must be correspondingly low.

As we know nothing absolutely about the water supply of Venus, we may reasonably assume that water is present in considerable quantity, as there is no reason for believing

that, in this respect, Venus differs very much from the earth. Then reasonable speculation will lead us to something like the following:

Strong winds prevail throughout all the regions bordering on the line separating darkness from light, the surface current coming out of the darkness and being cool, while the upper current is the very reverse. These winds, originating as they do in the sun's heat, would be a perpetual source of power. They also tend to equalize the temperature of the two hemispheres by carrying hot air from the light into the dark, and cold air from the dark into the light. And in passing from the middle of the lighter half to the middle of the other it is probable that the temperature, which would be high at the start, would gradually fall to a very low point at the finish. So that throughout a belt many degrees wide, lying along the border line, the temperature would be as varied as that prevailing upon the earth, the principal difference being that on Venus there is no change of season and no alteration of day and night. But each different region, in relation to the border line, has its own unchangeable climate and the sun perpetually fixed above or below its horizon.

The water carried by the upper winds is precipitated as rain or snow upon the border land, and the middle of the dark hemisphere is possibly covered by a large ice cap, while the surrounding regions are cool and moist, so that winds blowing from the dark portion of the planet are not only cool but well supplied with moisture.

Such a condition as that prevailing in the border land may be a very agreeable and acceptable one, and there is no reason why this belt may not be the abode of life. And when we remember that scarcely one-fourth of the surface of the earth is inhabitable land, it is quite possible that there may be even a larger portion of life on Venus than on the earth.

100. Mars.

This planet is considerably smaller than the earth, its diameter being about 4200 miles. But, owing to its axial rotation and the inclination of its equator to the plane of its

orbit, it has a regular return of day and night in a little over 24 hours, and an orderly rotation of seasons, and in these respects it offers conditions remarkably like those prevailing on the earth.

Its south hemisphere is best suited for observation because the south pole leans towards the earth when Mars is at its least distance from us.

But when either pole comes out from its long dark winter into the light and heat of the sun, it is seen to be surrounded by a large white polar cap, which gradually dwindles away to a comparatively small spot, or occasionally vanishes altogether, as the advancing Martian spring and summer warm up the polar regions.

These caps are now generally admitted to be snow, although the deposit is probably not as thick as is found about the terrestrial poles. The melting of this polar snow, at the advent of the Martian summer, shows that the temperature of Mars cannot be much different from that prevailing on the earth, and some astronomers have thought that the mean temperature of Mars may be even higher than that of the earth. We would expect the opposite on account of the greater distance of Mars from the sun, but it seems that temperature may be affected by other causes than mere distance.

The planet has an atmosphere which is probably not one-half as dense as the terrestrial one, but yet sufficiently so to give rise to twilight, and to support light dust clouds in its lower strata.

Water appears to be scarce on Mars, as there are no visible seas or lakes or rivers. And yet the atmosphere must contain a large amount to form the snows which cover over all the polar and a part of the temperate zones every year. This scarcity of water is probably due to the fact that, Mars being a small planet and older than the earth, the surface rocks have cooled so deeply that the former seas have penetrated into the interior.

The rocks of the earth a few miles below the surface are sufficiently hot to absolutely prevent water from penetrating

them. But when, in some millions of years, the earth, by the convection and radiation of its internal heat, becomes sufficiently cool to allow the seas to sink inwards, water will undoubtedly become as scarce upon the earth as it is now on Mars.

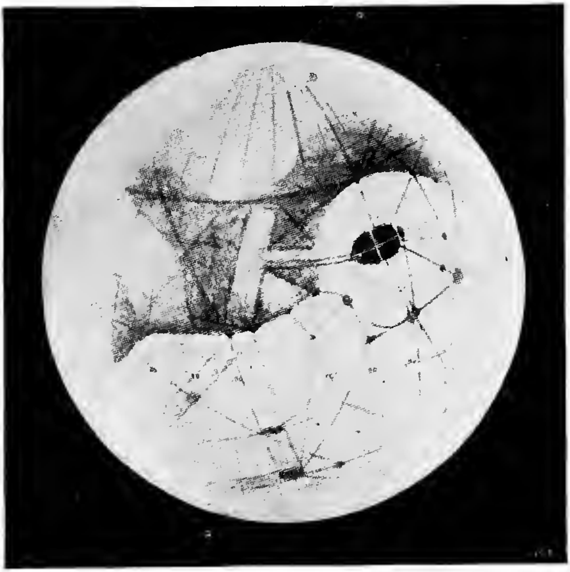


Fig. 94.

The figure is from a drawing by Lowell showing a view of Mars with some darker portions which are supposed to be ancient sea bottoms. As there are no high elevations on the planet it is likely that these sea bottoms are only shallow depressions, and that they no longer contain water.

The fine lines running in all directions and intersecting in well-defined points, or oases, through most of which several lines pass, are the celebrated *canals* of Mars. These were first seen by Schiaparelli, in 1877, from whom they

received the name *canali*. They are geodetic in form, or pursue the most direct route from point to point on the sphere, which seems to indicate that they are not accidental, but rather the results of intelligent action.

The canals are not always visible, but come into visibility soon after the polar snow cap begins to melt. They are very faint at first, but gradually grow darker and more distinct and new ones come into view farther away from the water supply. But whether faint or distinct they always occupy the same positions and have in them an element of permanency.

The theory of the canals, as it was proposed by W. H. Pickering and is generally accepted, is that what we see as a canal is a tract of irrigated country from 15 to 30 miles wide, along the middle of which runs an irrigation canal or ditch. That the water is supplied to this from the melting snow fields in the vicinity of the pole. And the various changes which a so-called canal is seen to undergo are due to changes in the vegetation of the irrigated district during the passing of the Martian spring and summer.

This explanation, of course, requires the existence of intelligent beings upon Mars, and if this is granted the theory amply accounts for the appearances as well as any theory can be expected to. But it may be here said that although a considerable number of astronomers believe in the canals and claim to have seen them, and have made drawings of them, yet there are some astronomers who, although supplied with large instruments, have never seen the canals and who doubt their existence.

But it is difficult to prove a negative. Those who desire fuller information on this subject are advised to read Percival Lowell's book "Mars," in which is set forth about all that has been done.

101. The Major Planets.

When we consider the great size and the low density of the major planets, we are forced to the conclusion that a

large part of their apparent bulk consists of gaseous matter, and that they must consequently be surrounded by very dense and extended atmospheres. The only feasible explanation of such a state of matters seems to be that the solid or liquid body of the planet is at a very high temperature—so high, in fact, that many more things exist in these atmospheres than in the atmospheres of the minor planets—or, in other words, that the major planets on account of their great size have not yet lost their primitive heat, and that their surfaces may still be red hot, or nearly so.

Of course, life cannot be existent under these circumstances. But when some hundreds of millions of years have passed away and all the minor planets have become cold and dead, then these giants may have their day of importance, and one after another may swarm with living creatures.

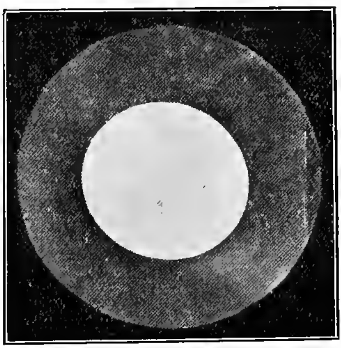


Fig. 95.

The accompanying figure shows the planet Jupiter as seen through the telescope. The disc is crossed by numerous dark bands parallel to the planet's equator, and known as the belts of Jupiter. These are most ~~distant~~ near the equator and are /dist undoubtedly great cloud masses drawn out in the banded form by the rapid axial rotation of the planet.

102. THE STARS.

The formal and systematic study of the stars constitutes a special department called stellar astronomy, and is of sufficient magnitude and importance to require a large treatise for its exposition. All that can be done in this work is to give the briefest outline of the subject.

Our sun is a star, the star that is nearest to us, and the one that we know best. And yet our knowledge of the sun, although more satisfactory than it was a hundred years ago, is far from being complete.

If we wish to know what a star is, the reasonable way is to study the sun, which, although only a third or fourth rate star, is yet typical of all the stars, as far as is known.

But the study of the sun is not easy. The sun is 93 millions of miles away and the smallest visible spot on its surface is not less than 100 miles across.

Besides, the condition of matters in the sun is so different from any thing on earth as to transcend all human experience if not human imagination.

Fancy, if you can, a globe so large that it would fill the moon's orbit twice over, and that this whole immense globe is one seething, boiling steaming mass, whose temperature is so high as to greatly transcend any temperature available on earth—so high that chemical compounds can not exist and all matter is resolved into its most elemental principles—where carbon and platinum and the most refractory substances are kept in a gasified state—where every thing is gaseous or ultra-gaseous and fluids and solids are non-existent—if you can fancy all this you may get some idea of the nature of the sun.

The most acceptable theory of the condition of the sun is about as follows:

The whole sun is gaseous, and therefore, in its exterior parts, at least, more mobile than a body of water. The interior is intensely hot, so that chemical combination is impossible. From this interior violent upward currents carry the glowing materials into the cooler atmosphere far above the *photosphere*, or principal light-giving layer of the sun.

Here they are sufficiently cooled to allow some forms of chemical combination to take place, and clouds are formed, somewhat after the manner in which terrestrial clouds are formed from water vapor being chilled in the upper air; but the solar clouds are not aqueous but vapors of iron, carbon, platinum, etc.

Then, as in the welshback burner, the solid mantle is intensely bright while its temperature is only that of the faintly luminous gas which surrounds it, so the solar clouds give off many times more light than the gases from which they were formed, although having a somewhat lower temperature.

These great cloud-patches form the bright spots which so thickly strew the sun's photosphere, while the uncombined gases form the darker background; for as seen through a proper telescope the sun presents a mottled appearance which Prof. Langley described as appearing like snow flakes upon a background of grey cloth.

The principal part of the sun's light comes from these spots, and from the *faculae* which appear like the intensely luminous crests of enormous waves.

Faculae are most numerous near sun spots, and both the spots and the faculae indicate violent commotion in that part of the photosphere. Thus the spectroscope has shown that movements as high as 320 miles a second often take place in the regions of a sun spot.

The solar clouds are heavier than the surrounding gases and quickly sink into the interior to be there dissipated and resolved anew into their gaseous constituents, and so to run the same course over again.

In the sun spot the uprush of matter from the interior is so violent that the surface of the photosphere is broken and forced apart, producing mountainous waves and sending spray to a height of some thousands of miles, forming the faculae and leaving in the light-giving surface a great depression anywhere from 1000 to 3000 miles deep, and in rare cases upwards of 100,000 miles across.

Into this depression the overlying and cooler gases rush with great velocity, and the depth of these in the cavity ab-

sorbs so much of the light from the brilliant mass beneath as to appear relatively dark against the intense brightness of the general surface. For it must be borne in mind that the darkest sun spot is brighter than the arc light.

In the midst of a total solar eclipse, when the dark body of the moon completely hides the body of the sun, the moon appears to be fringed here and there with fiery red projections which undergo rather rapid changes. This is the *chromosphere*, which is an outer gaseous envelope of the sun, too large to be completely covered by the moon, and having much less light-giving power than the photosphere. The chromosphere, which is probably 10,000 miles high or more, contains in its lower parts the vapors of all the elements, and in its higher parts the vapors of the lighter elements and especially hydrogen and helium in excess. The brilliant red color is due to incandescent hydrogen which gives a strong red line in the spectrum.

The upper layer of the chromosphere is singularly agitated by the upward rush of hot gases from below, and is occasionally projected outwards in great jets which attain a height of 15 or 20 thousand miles in a few hours.

Professor Young, who gave a great part of his life to studying the sun, says that " the appearance, which probably indicates a fact, is as if countless jets of heated gas were issuing through vents and spiracles over the whole surface, thus clothing it with flame which heaves and tosses like the blaze of a conflagration."

Lockyer saw at times the bright lines of the spectrum displaced and broken and distorted, plainly showing the presence of tremendous cyclonic storms in their passage along the solar surface. These storms had velocities as high, at times, as 250 miles per second. Comparing these with our greatest tornadoes, which scarcely ever exceed 100 miles an hour, we can form some faint idea of the state of matters in the sun. Hurricanes like these " coming down from the north would reach the Gulf of Mexico in about 30 seconds, carrying with them the whole surface of the continent in a mass, not simply of ruin, but of glowing vapor." This will

possibly give some faint idea of the fierceness of the action going on in the sun.

Young saw a vast hydrogen rosy-colored cloud 100,000 miles long floating above the photosphere at a height of 15,000 miles, and supported by upright columns or streamers by which it was supplied from below. In about 25 minutes after, this immense cloud had broken into a mass of débris consisting of violently agitated filaments. These rose to a height of 200,000 miles and gradually faded away.

Lockyer has seen a prominence fully 40,000 miles high shattered into confusion in ten minutes, while Respighi calculated that the initial velocities of some eruptions which he witnessed must have been over 400 miles per second, or greater than the critical velocity for the sun.

And the logical conclusion from such observations is that great quantities of hydrogen and other light material is continually escaping from the attraction of the sun and expanding itself in the boundless interstellar space.

The outermost appendage of the sun, if indeed it can be called an appendage, is the *Corona*. This is a faint halo of glory which surrounds the place of the sun when totally eclipsed, and it can be seen at no other times. Hence the interest which attaches to a total eclipse of the sun.

The corona is not an atmosphere, as it seems to be devoid of weight. It is unsymmetrical and variable in form, extending outwards at some times and in some directions to millions of miles. Its density is probably not one ten-thousandth part of the best vacuum that we can produce, for comets have been known to traverse parts of it at velocities as high as 200 miles per second or over without being sensibly checked in their courses.

The corona is probably matter, mostly in a corpuscular state. carried outwards from the sun by the repellant force of its fierce radiation. For it is now known that light rays exert a slightly repulsive force upon any object upon which they fall. And as this repulsion varies as the square of the diameter of a particle, while the weight or gravitation of the particle varies as the cube of the diamteer, in very finely

divided matter the repulsive force would overcome the gravitation of the particle and it would be driven outward into space.

But the sun is a third rate star; and every star is a sun in which the same forces are at play as in our sun, and in some cases with much greater activity, so that every star sends forth continually streams of radiant matter into surrounding regions, and thus the whole of interstellar space must be, figuratively speaking, "thronged with corpuscular traffic."

103. Distances and Comparative Sizes of the Stars.

By taking the diameter of the earth's orbit, 186 million miles, as a base, the parallaxes of a few stars have been determined, with a more or less degree of accuracy.

The star having the largest known parallax is *α Centauri*, its parallax being about 0″.67, which means that the star is at a distance of about 25 trillions of miles. Instead of dealing with these large numbers, astronomers have agreed to express stellar distances in *light-years*, in which the unit is the distance traversed by light in a year, at the velocity of 186,000 miles per second.

The following table gives the distances of some prominent stars in light-years:

α Centuari, the nearest star	4.2	lt.-yrs.
Sirius, the brightest star in the sky....	8.5	"
Procyon, the little dog star	10	"
Altair, the first star in the eagle......	14	"
Aldebaran, the bull's eye	30	"
Pollux, one of the twins	60	"
Arcturus, mentioned in Job	100	"
Regulus, the lion's heart	140	"

This list includes only prominent stars, and not all the stars whose distances have been measured.

In their first attempts at finding the distances of the stars, astronomers made the natural mistake of supposing that the larger and brighter stars were the nearer. But that this is not so is shown by the fact that Regulus and Arcturus are

very much brighter than α Centauri and yet many times farther away.

The star known as 61 Cygni is barely visible to the eye, but has a large proper motion, that is, it changes its place in the heavens to a considerable extent in each year. And yet its distance is determined to be about 7 lt.-years. So we see that the stars with the largest proper motion are not necessarily the nearest.

Again the star *Canopus* or α *Argus* is next to Sirius in brilliancy, although it has never shown any sensible parallax, and its distance is consequently not less than 200 light-years, and how much more we have no means of knowing.

We see, then, that the stars vary immensely not only in distance but also in size; for Canopus is brighter than Procyon and is not less than 20 times as far away; so that if Canopus were in the position of Procyon it would be about 400 times as bright as Procyon is. And if the temperatures of the two stars are about the same, it follows that Canopus must be somewhere like 8000 times as large as Procyon.

Again, Elkins has shown that the average distance of the 10 brightest stars is 33 lt.-years.

At this distance our sun would appear as a 5th magnitude star, or a star just faintly visible. So that our glorious sun does not hold a high rank among stars. If Sirius were at the sun's distance it would be 360 times as bright as the sun. But brightness varies as the square of the diameter and volume as the cube, so that if the sun and Sirius have the same temperature, Sirius must be something like 7000 times as large as the sun.

But Sirius is believed to be much hotter than the sun, so that 7000 is probably considerably too large a number. Then what shall we say of Canopus, which is nearly as brilliant as Sirius, while being at least 20 times as far away.

104. Proper Motions of the Stars.

The name "fixed star" is only a relative term. Every star has its proper motion which, although apparently very small, goes on unchanged from year to year and thus accu-

mulates through the ages. And these accumulations will in time, say 75 or 80 million years, change to a considerable extent the features of the starry heavens.

Thus α Centauri has a proper transverse motion of 3″.7 per year. Now, knowing the distance of the star, we readily find that this means about 15 miles per second. In like manner it has been determined, approximately at least, that 61 Cygni travels across our line of vision at 38 miles per second, which is about twice the velocity with which our sun and solar system are moving through space; and a star known as 1830 Groombridge "scorches the way" at the rate of 200 miles per second. We are accustomed to speak of the great speed of a rifle ball, but the speed of Groombridge is 600 times as great.

By means of the spectroscope the astronomer is able to measure with some accuracy the velocity of a star along the line of sight. For when a star is approaching the earth or sun its spectrum-lines are displaced towards the violet end of the spectrum, and when going away from the sun the spectrum-lines are displaced towards the red end of the spectrum.

In this way are obtained the following:

Stars approaching,	Arcturus	40 mil. per sec.
	ξ Herculis	44 " " "
	γ Leonis	24 " " "
Stars receding,	Aldebaran	30 " " "
	Sirius	25 " " "
	θ Orionis	15 " " "

105. Double Stars.

By this term is meant a system of two stars which revolve about one another, or rather about their common mass centre. It is also called a binary system.

The first star shown to be double was 61 Cygni, but the number now known rises into the hundreds or even the thousands, so that they are no longer novelties in astronomy. In a few cases the star can be seen to be double by the naked eye, and in many cases by the telescope, but the majority of

the known doubles do not appear as such even under the highest powers of the telescope.

The star 61 Cygni was known to consist of two stars as far back as 1806, but it was left to Sir William Herschell to show that it is a veritable double by showing that the stars revolve about one another.

The star α Centauri is also a double, the constituents being nearly equal, and about 17″, or 1,900,000,000 miles apart. And they complete a revolution in 81 years. From this it is derived that the mass of α Centauri is about twice the mass of the sun.

Sirius, also, is a double star. The diameter of the orbit of the Sirian system is 3,500,000,000 miles, and the period of revolution is 52 years. The *comes* is about $^4/_{10}$ as large as Sirius itself, and the mass of the system is $3\frac{1}{4}$ times that of the sun. So that the density of Sirius is less than the sun's density, and Sirius is much larger and brighter and hotter than the sun.

When a star cannot be seen to be double in the telescope, its true character may be revealed by the doubling of the lines in its spectrum. For if the earth lies anywhere near the plane of their orbit, one star will be receding from us when the other is approaching us, and the spectral lines of the stars will both be displaced, but in opposite directions; and as a consequence the spectra when overlapped will show all the lines doubled. The amount of displacement shows the relative velocity of motion of the stars.

Thus *Mizar*, a star in the handle of the dipper, has been shown, in this way, to be a remarkable double in which the stars are 22,000,000 miles apart and complete their circuit in 21 days.

β Aurigae is another spectroscopic double in which the stars travel at the rate of 65 miles a second, and have a combined mass 4.7 times that of the sun.

106. Variable Stars.

If one of the members of a binary system were much darker than the other and in its revolution came between the

bright member and the earth, the brightness of the system would suffer a periodic diminution, and the star would be a *variable.*

The most noted case of this kind is *Algol*, the "demon star of the Arabs." Algol is a star about 1,000,000 miles in diameter; its dark attendant is 830,000 miles in diameter, or about the size of our sun, and the time of revolution is 68.8 hours. The star Algol loses and gains $^3/_5$ of its brilliancy in a period of a few hours.

A number of other stars act in the same way as Algol, but there are numerous other variable stars whose manner of variation seems to be more or less arbitrary and irregular and of which no reasonable explanation seems yet to be forthcoming.

107. Star Clusters.

The group of stars known as the seven stars, or pleiades, is a coarse or open star cluster, as all the stars of the group appear to be in some way connected together, and long exposed photographs of the group show that the members are more or less encompassed by a common nebulous mass.

A cluster called Praesepe, or the bee-hive, in the constellation of Cancer, is smaller and more compact than the pleiades, the whole group appearing as a faint hazy spot to the unassisted sight. To the ancient Greeks, according to Aratus, its becoming dim and disappearing was an indication of coming rain; a very natural weather sign, as the faint light of the cluster is readily quenched in an atmosphere not altogether clear.

A still more magnificent cluster, designated as 5 M *librae* and appearing as a faint star, contains, according to Sir Wm. Herschel, more than 200 stars.

But according to the same authority the most magnificent cluster in the visible universe is the "star" known as ω *Centauri*, in which minute stars are too numerous to be counted, and are so closely compressed towards the centre of the cluster as to form a blaze of light.

As to the nature of a star cluster of the closer kind, such as ω Centauri, or, in fact, of any kind, almost nothing can be said to be known, except that it offers a field for unlimited speculation. Whatever the cause may be, star clusters appear to be particularly rich in variable stars, but how these variables are related to the general stars of the cluster, or in what way they depend upon the cluster for their variability, are questions as yet unanswered.

Fig. 96.

Are the stars of a cluster, like ω Centauri, smaller than the average stars of the universe, or is their faintness due to immensity of distance? Are they comparatively close together so that neighboring ones may influence each other, or are they as far apart relatively to their size as stars in more open parts of the skies? By what means have they become compacted together and separated from the great body of visible stars, or are they separate and distinct universes in themselves? All of these questions press for answers, but none of them, so far, have been answered.

108. The Milky Way.

This is the name given to that faint and irregular band of light which is seen to cross the skies from a northern point to a southern one, and which of course, in a way, may be said to rise and set every night. A volume might be written upon the wonders of the milky way, and upon the various speculations which have been indulged in and the theories which have been advanced with regard to its nature and constitution. And yet astronomers know very little more about the real character of this enigma to-day than did some of the ancient Greeks. Democritus and Pythagoras both held that the milky way was nothing more or less than a vast assemblage of stars, and Ovid speaks of it as a high road "whose ground work is of stars."

Fig. 97.

The faint luminosity of the milky way is due to the combined light of myriads of stars forming something like the juxtaposition of thousands of star-clusters in which many of the constituents are too faint and too close to be separated even by the higher powers of the telescope. Where the milky

way is brightest, there the stars are thickest or most compacted. Sir Wm. Herschel estimated that 116,000 stars passed through the field of his telescope in 15 minutes; and upon another occasion 258,000 stars passed in 41 minutes.

The groups of star-clusters which form the milky way are in no places separate and distinct, but run into one another with endless confusion, and apparently devoid of any arrangement or system whateyer.

The accompanying photograph of a small portion of the milky way, in the vicinity of Sagittarius, will give a better idea of its general appearance than a volume of description. The darkest parts are the general ground of the sky, and all the various gradations of light are due to fields of stars.

It would be in vain to enter upon any speculations regarding its internal constitution or its meaning in the universe, for beyond what is revealed through the telescope and photograph, nothing whatever can be said to be known about this mystery of the ages.

109. Nebulae.

The nebulae form another group of the mysterious and unexplainable things in the heavens.

A nebula appears as a faint hazy spot, without definite form, and illy defined even in the telescope. Two large ones, the great nebula of Orion, and the nebula of Andromeda, are barely visible to the naked eye, but the rest are telescopic. With low powers of the telescope it is easy to confound a faint star cluster with a nebula, while under high powers the distinction is apparent in the fact that some seeming nebulae have been resolved into stars, while others have not. It was consequently thought, at once, that all nebulae might be shown to be star clusters under sufficiently high powers of the telescope. But the spectroscope has shown that such an inference is untenable, as the spectra of the two things are quite different, and that the spectrum of a nebula contains a line which is found nowhere else, and which is attributed to some substance called *nebulum*, which is totally unknown anywhere except in a nebula.

Nebulae exist by hundreds and are most thickly distributed in those parts of the heavens which might be called the temperate and polar regions of the milky way, that is, in those regions which are quite removed from the milky way. No explanation of such a distribution is forthcoming.

Within the boundaries of many of the nebulae numerous stars may be seen. If the stars are between us and the nebulae the distance of the latter must be exceedingly great, and their size must surpass the powers of human imagination. And if the stars lie beyond the nebula and are seen through its depths, it is difficult to conceive of a substance so rare as to be unable to quench the light of the faintest star and yet to be itself visible. In fact, the great puzzle has been, and is

Fig. 98.

still, as to how a substance so rare as a nebula must be, whatever may be its physical state, can be visible by its own inherent light. The hypothesis of the "corpuscular traffic of the universe," already spoken of, may be in the line of an explanation. For the moving corpuscle meeting the particle of

nebulous matter with a velocity comparable to that of light may set up corpuscular vibration sufficient to make the particle visible, and thus the faint light of the nebula would come from its superficial parts only, and not from its interior. But this is mere hypothesis, and may or may not be fact.

Many of the nebulae, if not the great majority of them, have a distinctly spiral conformation, suggesting a rotation about an axis. The photograph here shown is of the spiral nebula of Ursa Major, and shows the conformation exceedingly well.

The outlying portions show small tufts of nebulous matter as if about to be thrown off by centrifugal force, and this has strengthened the hypothesis that nebulae are in some way the parents of stellar and planetary systems. But as a matter of fact the origin, development, and final destiny of the nebulae are among the profound secrets of the universe.

110. Comets.

A comet is a comparatively small mass of cosmic matter which travels through space in some one of the curves known as conic sections. If the comet is confined to the solar system, as Halley's and several other comets, the orbit is an ellipse, and however far away the body may go in its journey outwards from the sun, it will invariably return in time to its perihelion passage. Thus Halley's comet goes outward to beyond the orbit of Neptune, and passes its perihelion within the orbit of Venus.

But if the orbit be any of the other conic sections, as the parabola or the hyperbola, the comet, after passing the sun, will drift away into space, never to return to the solar system.

The distinctive feature of the majority of visible comets is the presence of a tail, which may be straight or be slightly curved, but which is always directed away from the sun. But some comets never develop tails, and the tail is never a very conspicuous appendage except when the comet is in some proximity to the sun. And thus the existence of a tail

is dependent partly on the nature of the comet itself, and partly upon some effect produced on the comet by the sun.

The mass of even the largest comet is exceedingly small, for when a comet, in its visit to the sun, passes near one of the planets of the solar system, the comet is always much disturbed and its course seriously interfered with, while the planet suffers no appreciable disturbance whatever. And from many considerations it appears doubtful if the mass of the largest comet is as much as one-millionth part of that of the moon.

And yet the nucleus of some comets, as that of 1845, was larger than this earth, while the enveloping *coma*, or surrounding layers, is sometimes more than a million miles across.

The only reasonable idea, then, that we can form of the constitution of a comet seems to be that its nucleus consists of an immense extent of small mineral pieces varying from mere dust particles upwards to a few larger ones scattered here and there, the whole reaching over thousands of miles, and having the particles exceedingly small as compared with the distances between them.

These particles, large and small, become luminous under the solar rays and give out light something after the manner of the motes which float in a sunbeam.

The coma must consist of still smaller particles, or of particles much more widely separated, or possibly of large quantities of exceedingly diffuse gaseous matter.

The constituent particles of a comet may contain any kind of matter, solid or liquid, and in a large number of cases the spectroscope has shown that the comet is rich in hydrocarbons. Out in the low temperatures of the farther reaches of the orbit much of this hydrocarbonacious matter might be liquid or even solid. But upon drawing near to the sun, the heat would volatilize it, and possibly some other substances, and the closer the proximity to the sun the greater would be the amount of gaseous hydrocarbons in the comet's constitution.

The particles of these vapors, exposed continuously to the fierce rays of the sun, are, in part at least, driven out into space with practically the velocity of light, and are finally dissipated and scattered to swell the amount of "corpuscular traffic."

This forms the tail which grows as the comet approaches the perihelion, which is essentially and necessarily opposite the sun, and which is not a permanent appendage of the comet, but which is being continually dissipated and as continually renewed from cometary resources.

Thus a comet loses something of its substance every time it makes its perihelion passage, and it is generally recognized that those comets which have returned to their perihelion a number of times have gradually grown smaller and less imposing, while a few have been quite lost.

A comet containing no hydrocarbons, or other volatile substances, cannot develop a tail.

For long ages comets have been looked upon as harbingers of evil and imminent sources of serious harm to the world and its inhabitants. Even so late as the year 1910 several persons committed suicide through fear of being destroyed by Halley's comet. This fear was helped on by the senseless statements of would-be sensational astronomers. And there is no more arrant humbug in existence than the man who is always threatening humanity with the disasters which are coming to the world from celestial sources.

The probability of the earth coming into direct collision with a comet is too remote to be worth considering, and even if such a collision should take place, it is not likely that the earth would be treated to anything more serious than a brilliant meteoric display, in which some harm might be done, but not as much as in a disastrous hurricane.

And as for being poisoned broadcast by passing through the tail of a comet, it is pretty certain that our globe has passed through the tails of several comets without the fact being recognized by the unobservant inhabitant. According to Hind, the earth penetrated the tail of the comet of 1861, producing nothing more serious than a faint glow in the

upper atmosphere; according to Klinkerfues, the earth passed through a great part of Biela's comet in 1872, giving to the people on the advancing side of the earth a brilliant and pleasing display of celestial fireworks; and it is quite certain that it was swept by the tail of Halley's comet on the 18th of May last, while thousands of people slept on quietly without knowing that anything out of the common was taking place.

The heavens are replete with wonder and mystery, and the few years of civilized man upon the earth are but as a moment in the long ages required for any material change to take place in the general character of the universe, or in the aggregation of the stars, or in the conformation of a nebula.

After pursuing his calling for ten thousand years or more, the astronomer will be in a better position than he is now to pronounce upon the validity and reasonableness of the theories and hypotheses which are current to-day. But it is not to be expected that an existence, even as long as the future duration of the earth itself, would enable him to solve in a manner completely satisfactory a moiety of the problems which present themselves for solution.

So the astronomer need have no fear that he will exhaust the wonders and mysteries of the mighty expanse, or be left without new things to be discovered and explained, for, however far his life may reach into the future, his work will be only a beginning in the knowing and understanding of the practically infinite.

INDEX.

Numbers refer to pages.

Aberration of Stars 163
Albedo 107
Almucantur 16
Altitude 16
Angle of the Vertical 37
Annus magnus 90
Anomalistic year 100
Anomaly 100
Antarctic Circle.......... 71
Aphelion 57
Apogee 49
Apsis line 49
Arctic Circle 71
Ascending Node 31
Autumnal equinox 62
Axis major 48
Axis minor 48
Azimuth 16

Bore 52

Canal, level of 8
Canals of Mars 185
Celestial latitude 74
" longitude 74
" points and lines.. 24
" sphere 5
Centre of gravity 50
Chromosphere 190
Circle of Perpet. App. ...20, 97
Circle of Perpet. Occult. .22, 97
" of altitude 16
Climate 100
Comets 201
Comparison of ⊕ and ⊙. 55
Conditions for atmosphere. 167
Conjunction, inf. and sup.. 148
Constellation 3
Conventional Zodiac 93
Corona 191
Critical Velocity 168
Culmination 25

Declination 26
Direct and Retrograde 148
Dominical letter 140
Double stars 194
Dynamic sun 80

Earth 6
Earth's axial rotation 18
" dimensions 34
" rotundity 6
Easter 139
Eccentricity 48
" error 80
" of orbit 100
Eclipses 115, 158
" duration of 121
" lunar 119

Eclipses in a year......... 135
" occurrence of 127
" periodicity of 134
Eclipse liimts 128
" periods 131
" maps 126, 127
Ecliptic 59
Ellipse 47
Epact ... .104, 140
Equation of light 162
" of time 81
Equator 15
Equatorial 32
Equinoctial year 91
Equinox 31, 62

Faculae 189
First meridian 31
" point of Aries 31
Foci 48
Formula $s=r\theta$ 33
Foucault's pendulum 22
Full moon 106

Gibbous 106
Golden number 105, 139
Gravitation 9
Great circle 15
Gregorian calendar 142

Harvest moon 110
Horizon 12
Horizontal parallax 41
Hunter's moon 110

Julian calendar 141
Jupiter 156
Jupiter's moons 157

Kepler's law I 47
" " II 57
" " III 146
Latitude 26, 37, 74
" correction of 37
Leap year 91
Level, the 11
Level line 7
Limb 39
Local meridian 25
Longitude 29, 74
" finding of 160
Lunation 104

Major planets 186
Mass centre 50
Mars ... .153, 183
" moons of 156
Mean day 80
" sun 80
" time 81
Meridian 16
" local 25
Meteors 176
Metonic cycle 138
Milky way 197
Moon ... .39, 102, 178
" diameter of 44
" distance of 42
" stereograph of 114
" wet and dry 108
Moon's diurnal aug. 46
" diurnal parallax ... 41
" horizontal parallax. 41
" libration 112
" motion 102
" nodes 133
" orbit 49, 108

Moon's parallax in altitude 42
" siderial period 103
" synodic period 104
Moon light and earth light 107
Movements of the stars.... 193

Nadir 13
Nebulae 199
Nebulum 199
New moon 106
Nodes 61
" motion of moon's... 133
Noon mark 83
North and south line...... 16
North star 19
Number of stars 3
Nutation 114

Old and new style......... 142
Old moon in new moon's arms 108
Obliquity of ecliptic 59
Obliquity error 80
Opposition 154
Order of planets 143

Parallax 38
" of moon 39
" of sun 54, 152, 156
" of stars 192
Penumbra 116
Photosphere 188
Planets 143
Progression of light 161
Perigee 49
Perihelion 57
Plumb line 10
Polaris ... .19, 95
Polaris on meridian 28
Pole star 19, 95
Poles 15
Precession of equinoxes .. 90
Prime vertical 16

Radius vector 57
Refraction 174
Retrograde motion 148
Right ascension 30

Saros, the 136
Saturn 164
Sea-level 11
Sea Offing 7
Seasons 69
Shadows 117
Siderial clock 78
" day 78
" time 77
" year 85
Solar day 81
" noon 81
" time 81
" system 142
Spheroidal earth 35
Star clusters 196
Stars 188
" number of 3
" fixed 5
Standard time 87
Summer stolstice 61
Sun ... .53, 188
Sun's distance 54, 164
" volume 56
" hor. parallax..54, 152, 156
" ang. diameter 57
" constitution 188

Sunday letter 140
Surface conditions 167

Temperature 172
Terminator 106
Terrestrial atmosphere ... 171
" sphere 5
Tides 51
Tidal action on moon...... 53
Time 77
Transit 25
" of Venus 150
Tropic of Cancer 71
" of Capricorn 73
Tropical year 91
True horizon 12
Two latitudes 36

Umbra 115

Variable Stars 195
Venus 147
Vernal equinox 31, 62
Visible horizon 12

Wanderings of pole 32
Wet and dry moon 109
Winds 173

Zenith 13
Zenith distance 16
Zodiac 64
" signs of 65
" ancient 68
" conventional 67, 93